



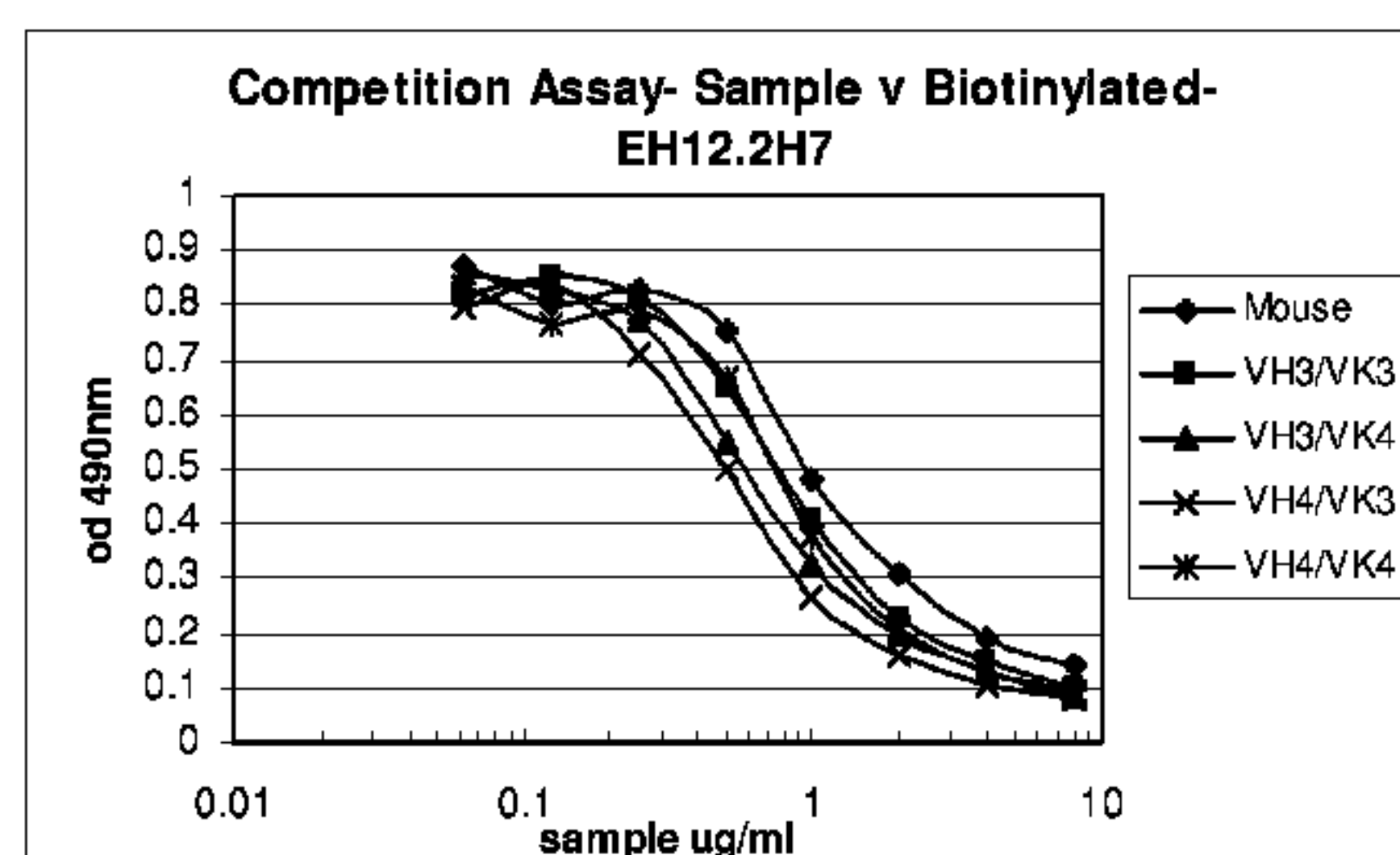
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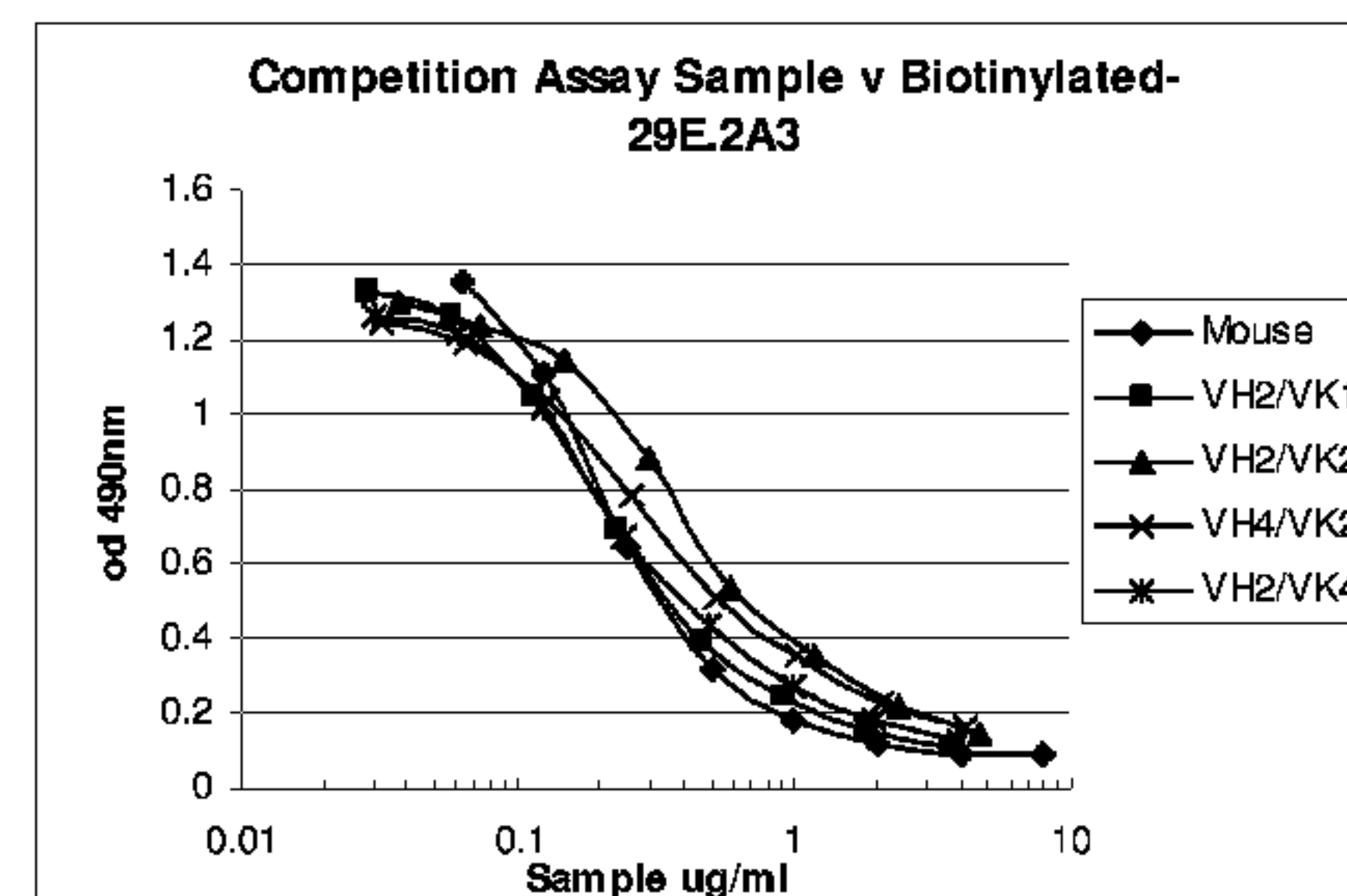
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(54) Title: HUMAN ANTI-PD-1, PD-L1, AND PD-L2 ANTIBODIES AND USES THEREFOR

Comparison of Composite, human Antibodies Activities to Mouse Reference
Antibody

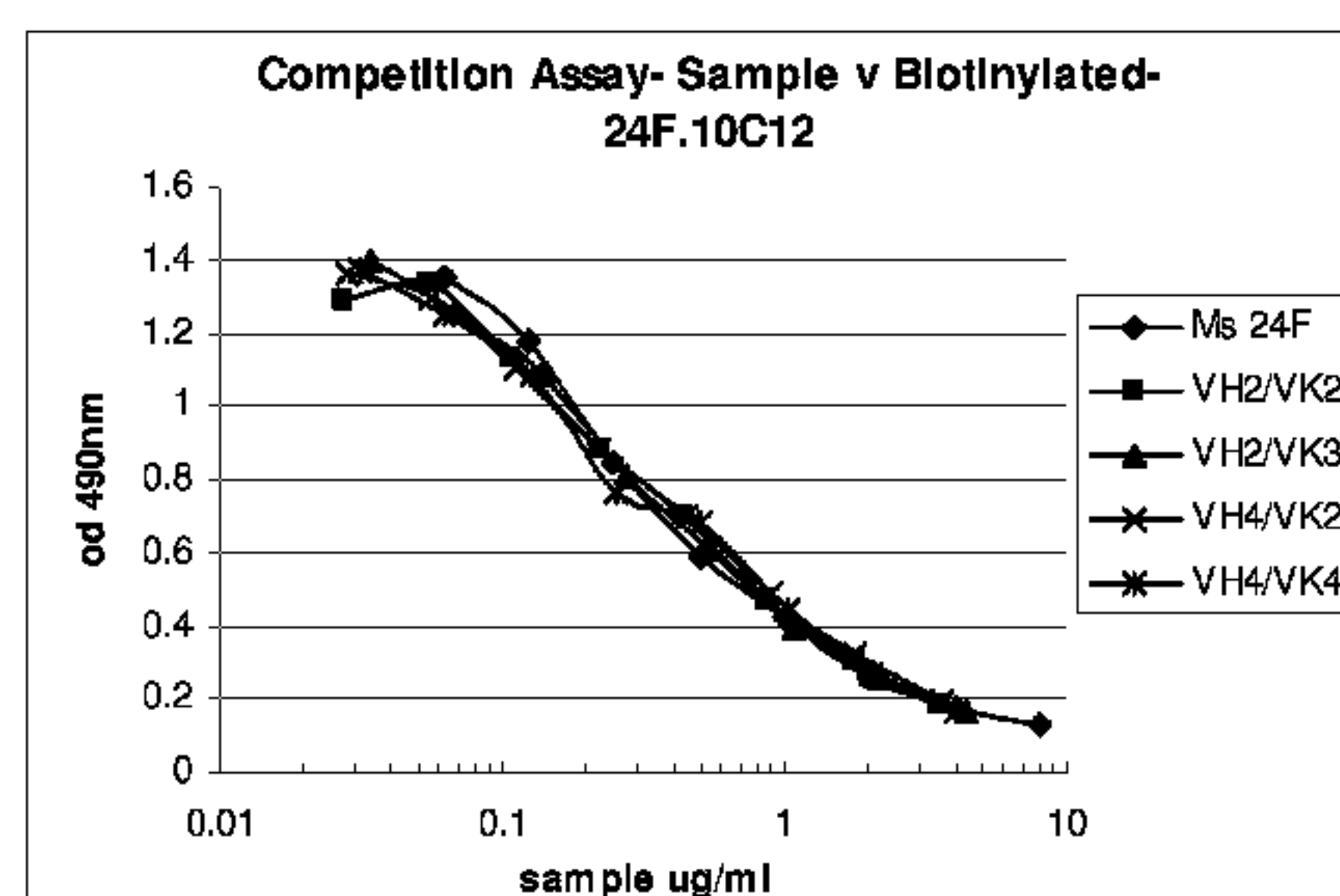
(A) Human PD-1 Competition ELISA:



(B) Human PD-L1 Competition ELISA:



(C) Human PD-L2 Competition ELISA:



(57) **Abrégé/Abstract:**

The present invention is based, in part, on the identification of novel human anti-PD-1, PD-L1, and PD-L2 antibodies. Accordingly, the invention relates to compositions and methods for diagnosing, prognosing, and treating conditions that would benefit from modulating PD-1, PD-L1, and/or PD-L2 activity (e.g., persistent infectious diseases, autoimmune diseases, asthma, transplant rejection, inflammatory disorders and tumors) using the novel human anti-PD-1, PD-L1, and PD-L2 antibodies described herein.

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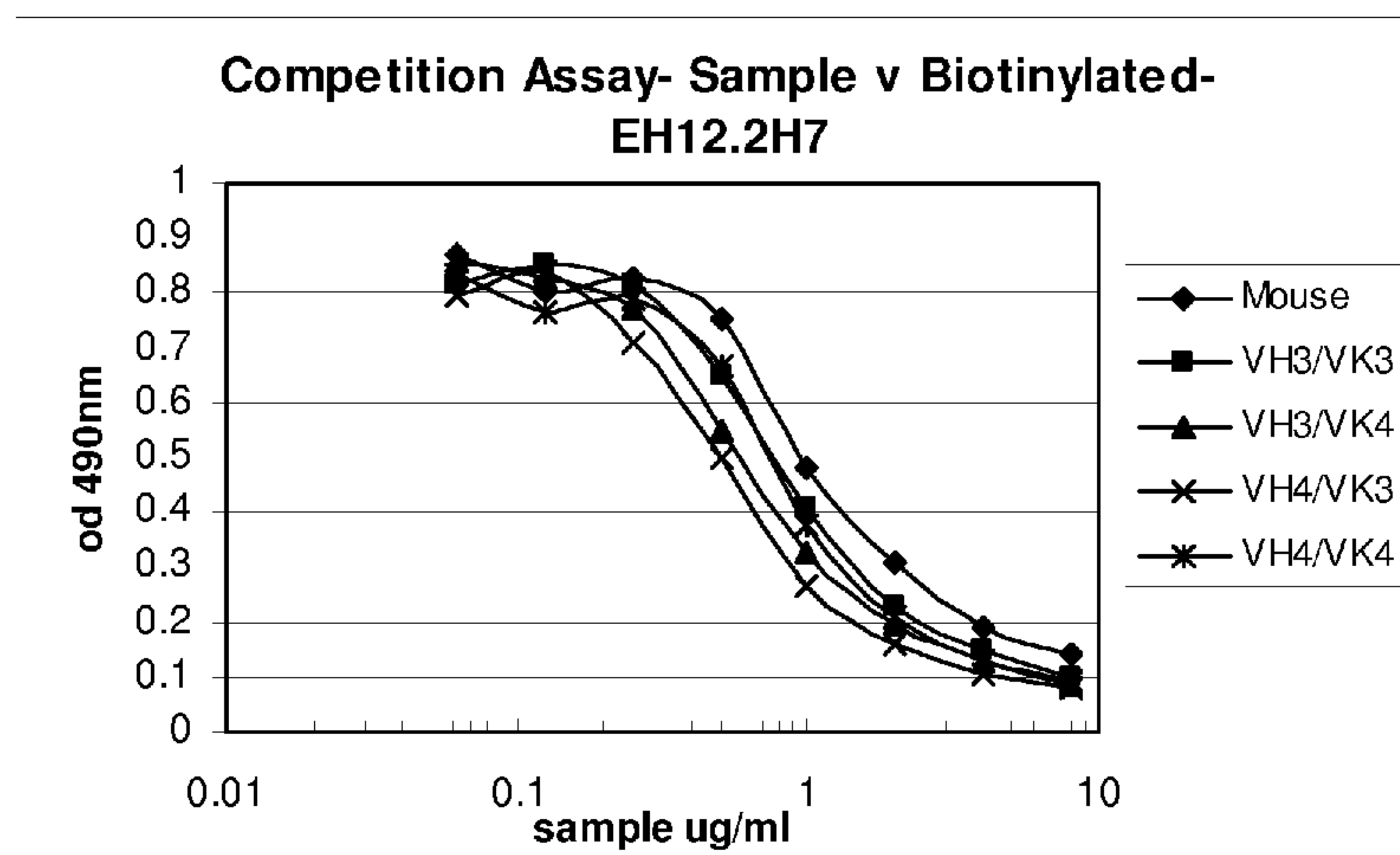
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[Continued on next page]

(54) Title: HUMAN ANTI-PD-1, PD-L1, AND PD-L2 ANTIBODIES AND USES THEREFOR

Figure 9. Comparison of Composite, human Antibodies Activities to Mouse Reference Antibody

(Figure 9A) Human PD-1 Competition ELISA:



(57) Abstract: The present invention is based, in part, on the identification of novel human anti-PD-1, PD-L1, and PD-L2 antibodies. Accordingly, the invention relates to compositions and methods for diagnosing, prognosing, and treating conditions that would benefit from modulating PD-1, PD-L1, and/or PD-L2 activity (e.g., persistent infectious diseases, autoimmune diseases, asthma, transplant rejection, inflammatory disorders and tumors) using the novel human anti-PD-1, PD-L1, and PD-L2 antibodies described herein.

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HUMAN ANTI-PD-1, PD-L1, AND PD-L2 ANTIBODIES AND USES THEREFORRelated Applications

[0001] This application claims priority benefit of U.S. Provisional Application No. 61/100,534, filed September 26, 2008.

5 Background of the Invention

[0002] For T cells to respond to foreign polypeptides, at least two signals must be provided by antigen-presenting cells (APCs) to resting T lymphocytes (Jenkins, M. and Schwartz, R. (1987) J. Exp. Med. 165:302-319; Mueller, D. L. *et al.* (1990) J. Immunol. 144:3701-3709). The first signal, which confers specificity to the immune response, is transduced via the T cell receptor (TCR) following recognition of foreign antigenic peptide presented in the context of the major histocompatibility complex (MHC). The second signal, termed costimulation, induces T cells to proliferate and become functional (Lenschow *et al.* (1996) Annu. Rev. Immunol. 14:233). Costimulation is neither antigen-specific, nor MHC-restricted, and is provided by distinct cell surface molecules expressed by APCs (Jenkins, M. K. *et al.* (1988) J. Immunol. 140:3324-3330; Linsley, P. S. *et al.* (1991) J. Exp. Med. 173:721-730; Gimmi, C. D. *et al.* (1991) Proc. Natl. Acad. Sci. USA 88:6575-6579; Young, J. W. *et al.* (1992) J. Clin. Invest. 90:229-237; Koulova, L. *et al.* (1991) J. Exp. Med. 173:759-762; Reiser, H. *et al.* (1992) Proc. Natl. Acad. Sci. USA 89:271-275; van-Seventer, G. A. *et al.* (1990) J. Immunol. 144:4579-4586; LaSalle, J. M. *et al.* (1991) J. Immunol. 147:774-80; Dustin, M. I. *et al.* (1989) J. Exp. Med. 169:503; Armitage, R. J. *et al.* (1992) Nature 20 357:80-82; Liu, Y. *et al.* (1992) J. Exp. Med. 175:437-445).

[0003] The proteins B7-1 (CD80) and B7-2 (CD86) are critical costimulatory molecules (Freeman *et al.* (1991) J. Exp. Med. 174:625; Freeman *et al.* (1989) J. Immunol. 143:2714; Azuma *et al.* (1993) Nature 366:76; Freeman *et al.* (1993) Science 262:909). B7-2 plays a predominant role during primary immune responses, while B7-1, which is upregulated later during an immune response, may be important for prolonging primary T cell responses or costimulating secondary T cell responses (Bluestone (1995) Immunity 2:555).

[0004] CD28 is a ligand for both B7-1 and B7-2 that is constitutively expressed by resting T cells and increases in expression following T cell activation. Ligation of CD28 in conjunction with a TCR signal results in transduction of a costimulatory signal that induces T cells to proliferate and secrete IL-2 (Linsley, P. S. *et al.* (1991) J. Exp. Med. 173:721-730; Gimmi, C. D.

et al. (1991) *Proc. Natl. Acad. Sci. USA* 88:6575-6579; June, C. H. *et al.* (1990) *Immunol. Today* 11:211-6; Harding, F. A. *et al.* (1992) *Nature* 356:607-609). A second B7-1 and B7-2 ligand, CTLA4 (CD152), is homologous to CD28 but not expressed by resting T cells. CTLA4 expression occurs following T cell activation (Brunet, J. F. *et al.* (1987) *Nature* 328:267-270). Ligation of CTLA4 results in transduction of an inhibitory signal that prevents T cell proliferation and cytokine secretion. Thus, CTLA4 is a critical negative regulator of T cell responses (Waterhouse *et al.* (1995) *Science* 270:985) (Allison and Krummel (1995) *Science* 270:932). The third member of the CD28 family to be discovered is ICOS (Hutloff *et al.* (1999) *Nature* 397:263; WO 98/38216). Ligation of ICOS by its ligand (ICOS-L) results in high levels of cytokine expression, but limited T cell expansion (Riley J. L. *et al.* (2001) *J. Immunol.* 166:4943-48; Aicher A. *et al.* (2000) *J. Immunol.* 164:4689-96; Mages H. W. *et al.* (2000) *Eur. J. Immunol.* 30:1040-7; Brodie D. *et al.* (2000) *Curr. Biol.* 10:333-6; Ling V. *et al.* (2000) *J. Immunol.* 164:1653-7; Yoshinaga S. K. *et al.* (1999) *Nature* 402:827-32). If T cells are stimulated through the T cell receptor in the absence of a costimulatory signal, they become nonresponsive, anergic, or die.

[0005] The importance of the B7:CD28/CTLA4/ICOS costimulatory pathway has been demonstrated in vitro and in several in vivo model systems. Blockade of this costimulatory pathway results in the development of antigen specific tolerance in murine and human systems (Harding, F. A. *et al.* (1992) *Nature* 356:607 609; Lenschow, D. J. *et al.* (1992) *Science* 257:789 792; Turka, L. A. *et al.* (1992) *Proc. Natl. Acad. Sci. USA* 89:11102 11105; Gimmi, C. D. *et al.* (1993) *Proc. Natl. Acad. Sci. USA* 90:6586 6590; Boussiotis, V. *et al.* (1993) *J. Exp. Med.* 178:1753 1763). Conversely, expression of B7 by B7-negative murine tumor cells induces T-cell mediated specific immunity accompanied by tumor rejection and long lasting protection to tumor challenge (Chen, L. *et al.* (1992) *Cell* 71:1093 1102; Townsend, S. E. and Allison, J. P. (1993) *Science* 259:368 370; Baskar, S. *et al.* (1993) *Proc. Natl. Acad. Sci.* 90:5687 5690.). Therefore, manipulation of the costimulatory pathways offers great potential to stimulate or suppress immune responses in humans.

[0006] The discovery of more members of the B7-1 and CD28 families has revealed additional pathways that provide costimulatory and inhibitory second signals to T cells. One of the newer pathways is represented by the programmed death 1 (PD-1; also known as CD279) receptor and its ligands, PD-L1 (B7-H1; CD274) and PD-L2 (B7-DC; CD273). PD-1 is a member of the CD28/CTLA4 family that is expressed on activated, but not resting T cells (Nishimura *et al.*

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(1996) *Int. Immunol.* 8:773). Ligation of PD-1 by its ligands mediates an inhibitory signal that results in reduced cytokine production, and reduced T cell survival (Nishimura *et al.* (1999) *Immunity* 11:141; Nishimura *et al.* (2001) *Science* 291:319; Chemnitz *et al.* (2004) *J. Immunol.* 173:945).

- [0007] PD-L1 is a B7 family member that is expressed on many cell types, including APCs and activated T cells (Yamazaki *et al.* (2002) *J. Immunol.* 169:5538). PD-L1 binds to both PD-1 and B7-1. Both binding of T-cell-expressed B7-1 by PD-L1 and binding of T-cell-expressed PD-L1 by B7-1 result in T cell inhibition (Butte *et al.* (2007) *Immunity* 27:111). There is also evidence that, like other B7 family members, PD-L1 can also provide costimulatory signals to T cells (Subudhi *et al.* (2004) *J. Clin. Invest.* 113:694; Tamura *et al.* (2001) *Blood* 97:1809).
- 10 [0008] PD-L2 is a B7 family member expressed on various APCs, including dendritic cells, macrophages and bone-marrow derived mast cells (Zhong *et al.* (2007) *Eur. J. Immunol.* 37:2405). APC-expressed PD-L2 is able to both inhibit T cell activation through ligation of PD-1 and costimulate T cell activation, through a PD-1 independent mechanism (Shin *et al.* (2005) *J. Exp. Med.* 201:1531). In addition, ligation of dendritic cell-expressed PD-L2 results in enhanced dendritic cell
- 15 cytokine expression and survival (Radhakrishnan *et al.* (2003) *J. Immunol.* 37:1827; Nguyen *et al.* (2002) *J. Exp. Med.* 196:1393). The structure and expression of PD-1, PD-L1, and PD-L2, as well as signaling characteristics and functions of these molecules in the context of regulating T cell activation and tolerance (*e.g.*, therapeutic effects) are reviewed in greater detail in Kier *et al.* (2008) *Ann. Rev. Immunol.* 26:677. Manipulation of this and other costimulatory pathways offers great potential to
- 20 stimulate or suppress immune responses in humans and a need exists for compositions and methods useful for effecting such manipulations.

Summary of the Invention

- [0009] The present invention is based on the generation and isolation of novel composite, human monoclonal antibodies which specifically bind to human PD-1, human PD-L1, and human PD-L2, as well
- 25 as the characterization of such novel antibodies and the demonstration of their therapeutic value in treating a variety of conditions mediated by PD-1, PD-L1, and/or PD-L2. Common techniques used to humanize murine antibodies frequently produce humanized antibodies that have reduced antigen binding affinities compared to the original murine antibodies (Almagro and Fransson (2008) *Frontiers in Bioscience* 13:1619-1633; Foote and Winter (1992) *J. Mol. Biol.* 224:487-499; Hwang *et al.* (2005)

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Methods 36:35-42). Surprisingly, the composite, human antibodies of the present invention have been shown to bind to PD-1, PD-L1 or PD-L2 with affinities closely approximating those of the murine antibodies. Furthermore, conventional humanization techniques produce humanized antibodies that retain some murine sequence. As a result, such antibodies can retain immunogenicity when
 5 administered to humans. For example, the humanized antibody CAMPATH® elicits immunogenicity in about 50% of patients. The composite, human antibodies of the present invention, on the other hand, are completely derived from sequences of human origin. Therefore, they are likely to be significantly less immunogenic and more therapeutically effective and useful when administered to human patients than other anti-human PD-1, PD-L1, and/or PD-L2 antibodies. Accordingly, the
 10 composite, human antibodies of the present invention provide an improved means for treating and preventing disorders mediated by PD-1, PD-L1, and/or PD-L2, attributable in part to their unique specificity, affinity, structure, functional activity and the fact that they are derived from human antibody sequences. The present invention is also based on the discovery of new therapeutic applications, including treatment of persistent infectious diseases, asthma, inflammatory diseases, and
 15 cancers, by administering the composite, human antibodies described herein.

[0010] One embodiment of the invention is an isolated antibody, or an antigen-binding fragment thereof, that binds to a PD-1 protein, a PD-L1 protein, or a PD-L2 protein (such as human PD-1, PD-L1, or PD-L2 protein), wherein the isolated antibody, or antigen-binding fragment thereof, is chimeric, humanized, composite, or human, and comprising one, two, three, four, five, or six CDR
 20 sequences selected from the group consisting of SEQ ID NO: 7-24.

[0011] The invention also provides an isolated antibody, or an antigen-binding fragment thereof, that binds to a PD-1 protein (such as a PD-1 protein comprising the amino acid sequence of SEQ ID NO: 2), wherein the isolated antibody, or antigen-binding fragment thereof, is chimeric, humanized, composite, or human, and comprising a heavy chain variable region sequence comprising
 25 SEQ ID NOs: 7-9 (CDR1 sequence of SEQ ID NO: 7, CDR2 sequence of SEQ ID NO: 8, and CDR3 sequence of SEQ ID NO: 9) and/or a light chain variable region sequence comprising SEQ ID NO: 10-12 (CDR1 sequence of SEQ ID NO: 10, CDR2 sequence of SEQ ID NO: 11, and CDR3 sequence of SEQ ID NO: 12).

[0012] The invention also provides an isolated antibody, or an antigen-binding fragment
 30 thereof, that binds to a PD-L1 protein (such as a PD-L1 protein comprising the amino acid sequence of SEQ ID NO: 4), wherein the isolated antibody, or antigen-binding fragment thereof, is chimeric,

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humanized, composite, or human, and comprising a heavy chain variable region sequence comprising SEQ ID NOs: 13-15 (CDR1 sequence of SEQ ID NO: 13, CDR2 sequence of SEQ ID NO: 14, and CDR3 sequence of SEQ ID NO: 15), and/or a light chain variable region sequence comprising SEQ ID NO: 16-18 (CDR1 sequence of SEQ ID NO: 16, CDR2 sequence of SEQ ID NO: 17, and
 5 CDR3 sequence of SEQ ID NO: 18).

[0013] The invention also provides an isolated antibody, or an antigen-binding fragment thereof, that binds to a PD-L2 protein (such as a PD-L2 protein comprising the amino acid sequence of SEQ ID NO: 6), wherein the isolated antibody, or antigen-binding fragment thereof, is chimeric, humanized, composite, or human, and comprising a heavy chain variable region sequence comprising
 10 SEQ ID NOs: 19-21 (CDR1 sequence of SEQ ID NO: 19, CDR2 sequence of SEQ ID NO: 20, and CDR3 sequence of SEQ ID NO: 21), and/or a light chain variable region sequence comprising SEQ ID NO: 22-24 (CDR1 sequence of SEQ ID NO: 22, CDR2 sequence of SEQ ID NO: 23, and CDR3 sequence of SEQ ID NO: 24).

[0014] The invention also includes an isolated antibody, or an antigen-binding fragment
 15 thereof, that binds to a PD-1 protein, a PD-L1 protein, or a PD-L2 protein (such as human PD-1, PD-L1, or PD-L2 protein) wherein the isolated antibody, or antigen-binding fragment thereof, is chimeric, humanized, composite, and/or human, and comprising a heavy chain sequence selected from the group consisting of SEQ ID NO: 25-29, 34-38, or 43-47 or a sequence with at least about 95%, 96%, 97%, 98%, 99%, 99.5%, 99.9% or more identical homology to SEQ ID NO: 25-29, 34-38,
 20 or 43-47, and/or a light chain sequence selected from the group consisting of SEQ ID NO: 30-33, 39-42, or 48-51, or a sequence with at least about 95%, 96%, 97%, 98%, 99%, 99.5%, 99.9% or more homology to SEQ ID NO: 30-33, 39-42, or 48-51.

[0015] The invention also provides an isolated antibody, or an antigen-binding fragment thereof, that binds to a PD-1 protein comprising the amino acid sequence of SEQ ID NO: 2, wherein
 25 the isolated antibody, or antigen-binding fragment thereof, is chimeric, humanized, composite, or human, and comprising a heavy chain sequence selected from the group consisting of SEQ ID NO: 25-29, or a sequence with at least about 95%, 96%, 97%, 98%, 99%, 99.5%, 99.9% or more identical or homology to SEQ ID NO: 25-29, and/or a light chain sequence selected from the group consisting of SEQ ID NO: 30-33, or a sequence with at least about 95%,

96%, 97%, 98%, 99%, 99.5%, 99.9% or more identical or homology to SEQ ID NO: 30-33. For example, the antibody or antigen binding fragment thereof comprises a heavy chain variable region sequence of SEQ ID NO: 27 or 28, and a light chain variable region sequence of SEQ ID NOs: 32 or 33. In some embodiments, the antibody or antigen binding fragment thereof comprises a heavy chain variable region sequence of SEQ ID NO: 28, and a light chain variable region sequence of SEQ ID NOs: 32.

[0016] The invention also provides an isolated antibody, or an antigen-binding fragment thereof, that binds to a PD-L1 protein comprising the amino acid sequence of SEQ ID NO:4, wherein the isolated antibody, or antigen-binding fragment thereof, is chimeric, humanized, composite, or human, and comprising a heavy chain sequence selected from the group consisting of SEQ ID NO: 34-38, or a sequence with at least about 95%, 96%, 97%, 98%, 99%, 99.5%, 99.9% or more identical or homology to SEQ ID NO: 34-38, and/or a light chain sequence selected from the group consisting of SEQ ID NO: 39-42, or a sequence with at least about 95%, 96%, 97%, 98%, 99%, 99.5%, 99.9% or more identical or homology to SEQ ID NO: 39-42. For example, the antibody or antigen binding fragment thereof comprises a heavy chain variable region sequence of SEQ ID NO: 35 or 37, and a light chain variable region sequence of SEQ ID NO: 39, 40 or 42. In some embodiments, the antibody or antigen binding fragment thereof comprises a heavy chain variable region sequence of SEQ ID NO: 35, and a light chain variable region sequence of SEQ ID NO: 42.

[0017] The invention also provides an isolated antibody, or an antigen-binding fragment thereof, that binds to a PD-L2 protein comprising the amino acid sequence of SEQ ID NO:6, wherein the isolated antibody, or antigen-binding fragment thereof, is chimeric, humanized, composite, or human, and comprising a heavy chain sequence selected from the group consisting of SEQ ID NO: 43-47, or a sequence with at least about 95%, 96%, 97%, 98%, 99%, 99.5%, 99.9% or more identical or homology to SEQ ID NO: 43-47, and/or a light chain sequence selected from the group consisting of SEQ ID NO: 48-51, or a sequence with at least about 95%, 96%, 97%, 98%, 99%, 99.5%, 99.9% or more identical or homology to SEQ ID NO: 48-51. For example, the antibody or antigen binding fragment thereof comprises a heavy chain variable region sequence of SEQ ID NO: 44 or 46, and a light chain variable region sequence of SEQ ID NO: 49, 50 or 51. In some embodiments, the antibody or antigen binding fragment thereof comprises a heavy chain variable region sequence of SEQ ID NO: 46, and a light chain variable region sequence of SEQ ID NO: 51.

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- [0018]** Another embodiment of the invention is an isolated antibody described herein, or an antigen-binding fragment thereof, that binds to a PD-1 protein, wherein the isolated antibody inhibits the binding of biotinylated EH12.2H7 antibody to Fc-PD-1 in a competition ELISA assay. Another embodiment is an isolated antibody described herein, or an antigen-binding fragment thereof, that binds to a PD-L1 protein, wherein the isolated antibody inhibits the binding of biotinylated 29E2A3 antibody to Fc-PD-L1 in a competition ELISA assay. Another embodiment is an isolated antibody described herein, or an antigen-binding fragment thereof, that binds to a PD-L2 protein, wherein the isolated antibody inhibits the binding of biotinylated 24F.10C12 antibody to Fc-PD-L2 in a competition ELISA assay.
- [0019]** Another embodiment of the invention is an isolated antibody described herein, or an antigen-binding fragment thereof, that binds to a PD-1 protein, wherein the isolated antibody inhibits a PD-1-mediated signal. Another embodiment is an isolated antibody described herein, or an antigen-binding fragment thereof, that binds to a PD-L1 protein wherein the isolated antibody inhibits a PD-L1-mediated signal. Another embodiment is an isolated antibody described herein, or an antigen-binding fragment thereof, that binds to a PD-L2 protein wherein the isolated antibody inhibits a PD-L2-mediated signal.
- [0020]** In particular, an embodiment of the invention is an isolated nucleic acid encoding a polypeptide, wherein the polypeptide comprises a sequence selected from the group consisting of SEQ ID NO: 25-51, or a sequence with at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% or more identical or homology to SEQ ID NO: 25-51. Another embodiment is a vector, host cell or animal comprising one or more of these nucleic acids. Another aspect is a nucleic acid that hybridizes, under stringent conditions, with the complement of a nucleic acid encoding a polypeptide selected from the group consisting of SEQ ID NO: 25-51, or a sequence with at least about at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% or more identical homology to SEQ ID NO: 25-51.
- [0020A]** An embodiment of the invention relates to a nucleic acid that hybridizes, under stringent conditions, with the complement of a nucleic acid encoding a polypeptide selected from the group consisting of SEQ ID NOs: 34-42, wherein the stringent hybridization conditions comprise hybridization in 4x or 6x sodium chloride/sodium citrate (SSC), at 65-70°C followed by one or more washes in 1x SSC, at 65-70°C; hybridization in 4x SSC plus 50% formamide, at 42-50°C followed by one or more washes in 1x SSC, at 65-70°C; includes hybridization at 6x SSC at 45°C, followed by one or more washes in 0.2x SSC and 0.1% SDS at 65°C; hybridization in 1x SSC, at 65-70°C followed by one or more washes in 0.3x SSC, at 65-70°C; or hybridization in 1x SSC plus 50% formamide, at 42-50°C followed by one or more washes in 0.3x SSC, at 65-70°C.

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[0021] The invention also provides an isolated nucleic acid encoding a heavy chain variable region and/or a light chain variable region of any of the antibodies or antigen binding-fragments thereof described herein. In some embodiments, the nucleic acid is in a vector, such as an expression vector. The invention also provides a host cell comprising one or more nucleic acids encoding the heavy and/or light

5 chain of the antibodies or antigen-binding fragments described herein. In some embodiments, the host cell produces the antibodies or antigen-binding fragments. The invention also provides methods of producing the antibody or antigen-binding

fragment described herein, comprising culturing a cell that produces the antibody or antigen-binding fragment, and recovering the antibody or antigen-binding fragment from the cell culture.

[0022] The invention further includes a pharmaceutical composition, comprising an isolated antibody described herein, or an antigen-binding fragment thereof, and a pharmaceutically-acceptable carrier.

[0023] The invention encompasses a method of reactivating an exhausted T cell, comprising contacting a population of T cells wherein at least some cells express PD-, PD-L1 and/or PD-L2 using an antibody described herein or an antigen-binding fragment thereof either *in vitro*, *ex vivo*, or *in vivo*.

[0024] The invention further pertains to a method of treating a subject suffering from a persistent infection, including a viral infection, a bacterial infection, a helminth infection, or a protozoan infection, comprising administering to the subject a composition comprising an effective amount of an isolated antibody described herein, or an antigen-binding fragment thereof.

[0025] The invention further encompasses a method of treating cancer, comprising administering to the subject a composition comprising an effective amount of an isolated antibody described herein, or an antigen-binding fragment thereof, including wherein the isolated antibody induces antibody-mediated cytotoxicity or is modified to induce antibody-mediated cytotoxicity or conjugated to an agent selected from the group consisting of a toxin and an imaging agent. In some embodiments, the antibody or the antigen-binding fragment that binds to a PD-L1 is administered to the subject having a cancer over-expressing PD-L1. In some embodiments, the antibody or the antigen-binding fragment that binds to a PD-L2 is administered to the subject having a cancer over-expressing PD-L2.

[0026] The invention further pertains to a method of treating a subject suffering from asthma, comprising administering to the subject a composition comprising an effective amount of an isolated antibody that binds to a PD-L2 protein described herein, or an antigen-binding fragment thereof.

[0027] The invention also encompasses a method of treating a subject suffering from an inflammatory disease or transplant rejection, comprising administering to the subject a composition comprising an effective amount of an isolated antibody described herein, or an antigen-binding fragment thereof, that binds to a PD-L1 protein or a PD-L2 protein.

[0028] The invention also encompasses an antibody, an antigen-binding fragment or a polypeptide described herein for use in any of the methods described herein. The invention also encompasses the use of an antibody, an antigen-binding fragment or a polypeptide described herein for the manufacture of a medicament, such as a medicament for treating any of the diseases described herein in a subject.

Brief Description of the Drawings

[0029] **Figure 1** shows a schematic diagram of expression vectors used for cloning the assembled human immunoglobulin sequences of the present invention.

[0030] **Figures 2A-2E** show composite, human heavy chain (Figure 2A, VH1; Figure 2B, VH2; Figure 2C, VH3; and Figure 2D, VH4; Figure 2E, VH5) variable region sequences designed to correspond to that of the mouse anti-human PD-1 antibody, EH12.2H7.

[0031] **Figures 3A-3D** show composite, human light chain (Figure 3A, Vκ1; Figure 3B, Vκ2; Figure 3C, Vκ3; Figure 3D, Vκ4) variable region sequences designed to correspond to that of the mouse anti-human PD-1 antibody, EH12.2H7.

[0032] **Figures 4A-4E** show composite, human heavy chain (Figure 4A, VH1; Figure 4B, VH2; Figure 4C, VH3; Figure 4D, VH4; Figure 4E, VH5) variable region sequences designed to correspond to that of the mouse anti-human PD-L1 antibody, 29E.2A3.

[0033] **Figures 5A-5D** show composite, human light chain (Figure 5A, Vκ1; Figure 5B, Vκ2; Figure 5C, Vκ3; Figure 5D, Vκ4) variable region sequences designed to correspond to that of the mouse anti-human PD-L1 antibody, 29E.2A3.

[0034] **Figures 6A-6E** show composite, human heavy chain (Figure 6A, VH1; Figure 6B, VH2; Figure 6C, VH3; Figure 6D, VH4; Figure 6E, VH5) variable region sequences designed to correspond to that of the mouse anti-human PD-L2 antibody, 24F.10C12.

[0035] **Figures 7A-7D** show composite, human light chain (Figure 7A, Vκ1; Figure 7B, Vκ2; Figure 7C, Vκ3; Figure 7D, Vκ4) variable region sequences designed to correspond to that of the mouse anti-human PD-L2 antibody, 24F.10C12.

[0036] **Figures 8A-8C** show SDS-PAGE results of 1 μg of composite, human antibodies corresponding to the mouse anti-human antibodies, EH12.2H7, 29E.2A3, and 24F.10C12, respectively.

[0037] **Figure 9A-9C** show ELISA competition results of human antibodies corresponding to and relative to the mouse anti-human antibodies, EH12.2H7, 29E.2A3, and 24F.10C12,

respectively. In Figure 9A, the binding of the purified antibodies to human PD-1 was tested via competition ELISA. Varying concentrations of each antibody (0.06 $\mu\text{g/ml}$ to 8 $\mu\text{g/ml}$) were mixed with a fixed concentration of biotinylated EH12.2H7 (40 ng/ml) and bound to a PD-1 coated immulon maxisorb plate. Binding was detected via streptavidin-HRP and OPD substrate. Absorbance at 490 nm was measured on a plate reader and this was plotted against the test antibody concentration. In Figure 9B, the binding of the purified antibodies to human PD-L1 was tested via competition ELISA. Varying concentrations of each antibody (0.02 $\mu\text{g/ml}$ to 8 $\mu\text{g/ml}$) were mixed with a fixed concentration of biotinylated 29E.2A3 (40 ng/ml) and bound to a PD-L1 coated immulon maxisorb plate. Binding was detected via streptavidin-HRP and OPD substrate. Absorbance at 490 nm was measured on a plate reader and this was plotted against the test antibody concentration. In Figure 9C, the binding of the purified antibodies to human PD-L2 was tested via competition ELISA. Varying concentrations of each antibody (0.02 $\mu\text{g/ml}$ to 8 $\mu\text{g/ml}$) were mixed with a fixed concentration of biotinylated 24F.10C12 (40 ng/ml) and bound to a PD-L2 coated immulon maxisorb plate. Binding was detected via streptavidin-HRP and OPD substrate. Absorbance at 490 nm was measured on a plate reader and this was plotted against the test antibody concentration.

[0038] Figures 10A-10C show IC_{50} binding data resulting from ELISA competition analysis of composite, human antibodies formed according to different combinations of composite, human heavy and light chains designed to correspond to those of the mouse anti-human antibodies, EH12.2H7 (Figure 10A), 29E.2A3 (Figure 10B), and 24F.10C12 (Figure 10C), respectively. The assay was performed as described in Figure 3. The IC_{50} for each combination of heavy and light chain was normalized against the IC_{50} of the mouse antibody. ND = No Data.

[0039] Figure 11 shows the amino acid sequences of PD-1, PD-L1 and PD-L2.

[0040] Figure 12 shows the amino acid sequences of the CDR regions of some of the Composite, Human Antibodies described herein.

[0041] Figure 13 shows the amino acid sequences of the variable regions of some of the Composite, Human Antibodies described herein.

[0042] Figures 14A and 14B shows effect of a humanized anti-PD-1 antibody and a humanized anti-PD-L1 antibody on the proliferative capacity of SIV Gag-specific CD8 T cells in vitro. Each symbol represents an individual macaque. Numbers in parenthesis represent fold increase in proliferation in the presence of a blocking Ab compared to no blocking Ab.

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[0043] **Figure 15** shows that PD-L1 blockage restores antigen-driven proliferation of intrahepatic CD8 T cells (representative data from animal 1564).

Detailed Description of the Invention

[0044] The present invention provides novel antibody-based therapeutics for treating and
5 diagnosing a variety of disorders mediated by PD-1, PD-L1, and/or PD-L2 (*e.g.*, treatment of persistent infectious diseases, asthma, inflammatory diseases, transplant rejections and cancers).

[0045] In order that the present invention may be more readily understood, certain terms are first defined. Additional definitions are set forth throughout the detailed description.

[0046] As used herein, the terms “PD-1”, “PD-L1”, and “PD-L2” include any variants or
10 isoforms which are naturally expressed by cells, and/or fragments thereof having at least one biological activity of the full-length polypeptide, unless otherwise expressly defined. In addition, the term “PD-1 ligand” includes either or both PD-L1 (Freeman *et al.* (2000) *J. Exp. Med.* 192:1027) and PD-L2 (Latchman *et al.* (2001) *Nat. Immunol.* 2:261) and any variants or isoforms which are naturally expressed by cells, and/or fragments thereof having at least one biological activity of the full-length
15 polypeptides. For example, PD-1, PD-L1, and PD-L2 sequences from different species, including humans, are well known in the art (see, for example, Honjo *et al.*, U.S. Pat. No. 5,629,204, which discloses human and mouse PD-1 sequences; Wood *et al.*, U.S. Patent 7,105,328, which discloses human PD-1 sequences; Chen *et al.*, U.S. Patent 6,803,192, which discloses human and mouse PD-L1 sequences; Wood *et al.*, U.S. Patent 7,105,328, which discloses human PD-L1 sequences;
20 Freeman *et al.*, US Pat. Pub. 20020164600, which discloses human and mouse PD-L2 sequences).

[0047] As used herein, the term “antibody” includes whole antibodies and any antigen binding fragment (*i.e.*, “antigen-binding portion”) or single chain thereof. An “antibody” refers to a glycoprotein comprising at least two heavy (H) chains and two light (L) chains inter-connected by disulfide bonds, or an antigen binding portion thereof. Each heavy chain is comprised of a heavy
25 chain variable region (abbreviated herein as V_H) and a heavy chain constant region. The heavy chain constant region is comprised of three domains, CH1, CH2 and CH3. Each light chain is comprised of a light chain variable region (abbreviated herein as V_L) and a light chain constant region. The light chain constant region is comprised of one domain, CL. The V_H and V_L regions can be further subdivided into regions of hypervariability, termed complementarity

determining regions (CDR), interspersed with regions that are more conserved, termed framework regions (FR). Each V_H and V_L is composed of three CDRs and four FRs, arranged from amino-terminus to carboxy-terminus in the following order: FR1, CDR1, FR2, CDR2, FR3, CDR3, FR4. The variable regions of the heavy and light chains contain a binding domain that interacts with an antigen. “Inactivating antibodies” refers to antibodies that do not induce the complement system.

[0048] The term “*hypervariable region*,” “*HVR*,” or “*HV*,” when used herein refers to the regions of an antibody-variable domain that are hypervariable in sequence and/or form structurally defined loops. Generally, antibodies comprise six HVRs; three in the V_H (H1, H2, H3), and three in the V_L (L1, L2, L3). In native antibodies, H3 and L3 display the most diversity of the six HVRs, and H3 in particular is believed to play a unique role in conferring fine specificity to antibodies. See, *e.g.*, Xu *et al.* *Immunity* 13:37-45 (2000); Johnson and Wu in *Methods in Molecular Biology* 248:1-25 (Lo, ed., Human Press, Totowa, NJ, 2003)). Indeed, naturally occurring camelid antibodies consisting of a heavy chain only are functional and stable in the absence of light chain. See, *e.g.*, Hamers-Casterman *et al.*, *Nature* 363:446-448 (1993) and Sheriff *et al.*, *Nature Struct. Biol.* 3:733-736 (1996).

[0049] A number of hypervariable region delineations are in use and are encompassed herein. The Kabat Complementarity Determining Regions (CDRs) are based on sequence variability and are the most commonly used (Kabat *et al.*, *Sequences of Proteins of Immunological Interest*, 5th Ed. Public Health Service, National Institutes of Health, Bethesda, MD. (1991)). Chothia refers instead to the location of the structural loops (Chothia and Lesk *J. Mol. Biol.* 196:901-917 (1987)). The end of the Chothia CDR-H1 loop when numbered using the Kabat numbering convention varies between H32 and H34 (see below) depending on the length of the loop (this is because the Kabat numbering scheme places the insertions at H35A and H35B; if neither 35A nor 35B is present, the loop ends at 32; if only 35A is present, the loop ends at 33; if both 35A and 35B are present, the loop ends at 34). The AbM hypervariable regions represent a compromise between the Kabat CDRs and Chothia structural loops, and are used by Oxford Molecular’s AbM antibody modeling software. The “contact” hypervariable regions are based on an analysis of the available complex crystal structures. The residues from each of these hypervariable regions are noted below.

Loop	Kabat	AbM	Chothia	Contact
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L1	L24-L34	L24-L34	L24-L34	L30-L36
L2	L50-L56	L50-L56	L50-L56	L46-L55
L3	L89-L97	L89-L97	L89-L97	L89-L96
H1	H31-H35B	H26-H35B	H26-H32, 33 or 34	H30-H35B (Kabat Numbering)
H1	H31-H35	H26-H35	H26-H32	H30-H35 (Chothia Numbering)
H2	H50-H65	H50-H58	H52-H56	H47-H58
H3	H95-H102	H95-H102	H95-H102	H93-H101

[0050] Hypervariable regions may comprise “extended hypervariable regions” as follows: 24-36 or 24-34 (L1), 46-56 or 50-56 (L2) and 89-97 (L3) in the VL and 26-35B (H1), 50-65, 47-65 or 49-65 (H2) and 93-102, 94-102 or 95-102 (H3) in the VH. These extended hypervariable regions are typically combinations of the Kabat and Chothia definitions, which may optionally further include residues identified using the Contact definition. The variable domain residues are numbered according to Kabat *et al.*, *supra* for each of these definitions.

[0051] “*Framework*” or “FR” residues are those variable-domain residues other than the HVR residues as herein defined.

[0052] The expression “variable-domain residue-numbering as in Kabat” or “amino-acid-position numbering as in Kabat,” and variations thereof, refers to the numbering system used for heavy-chain variable domains or light-chain variable domains of the compilation of antibodies in Kabat *et al.*, *supra*. Using this numbering system, the actual linear amino acid sequence may contain fewer or additional amino acids corresponding to a shortening of, or insertion into, a FR or HVR of the variable domain. For example, a heavy-chain variable domain may include a single amino acid insert (residue 52a according to Kabat) after residue 52 of H2 and inserted residues (*e.g.* residues 82a, 82b, and 82c, *etc.* according to Kabat) after heavy-chain FR residue 82. The Kabat numbering of residues may be determined for a given antibody by alignment at regions of homology of the sequence of the antibody with a “standard” Kabat numbered sequence.

[0053] The term “*Fc region*” herein is used to define a C-terminal region of an immunoglobulin heavy chain, including native-sequence Fc regions and variant Fc regions. Although the boundaries of the Fc region of an immunoglobulin heavy chain might vary, the human IgG heavy-chain Fc region is usually defined to stretch from an amino acid residue at

position Cys226, or from Pro230, to the carboxyl-terminus thereof. The C-terminal lysine (residue 447 according to the EU numbering system) of the Fc region may be removed, for example, during production or purification of the antibody, or by recombinantly engineering the nucleic acid encoding a heavy chain of the antibody. Accordingly, a composition of intact antibodies may comprise antibody populations with all K447 residues removed, antibody populations with no K447 residues removed, and antibody populations having a mixture of antibodies with and without the K447 residue. Suitable native-sequence Fc regions for use in the antibodies of the invention include human IgG1, IgG2 (IgG2A, IgG2B), IgG3 and IgG4.

[0054] “*Fc receptor*” or “*FcR*” describes a receptor that binds to the Fc region of an antibody. The preferred FcR is a native sequence human FcR. Moreover, a preferred FcR is one which binds an IgG antibody (a gamma receptor) and includes receptors of the FcγRI, FcγRII, and FcγRIII subclasses, including allelic variants and alternatively spliced forms of these receptors. FcγRII receptors include FcγRIIA (an “activating receptor”) and FcγRIIB (an “inhibiting receptor”), which have similar amino acid sequences that differ primarily in the cytoplasmic domains thereof. Activating receptor FcγRIIA contains an immunoreceptor tyrosine-based activation motif (ITAM) in its cytoplasmic domain. Inhibiting receptor FcγRIIB contains an immunoreceptor tyrosine-based inhibition motif (ITIM) in its cytoplasmic domain. (see M. Daëron, *Annu. Rev. Immunol.* 15:203-234 (1997). FcRs are reviewed in Ravetch and Kinet, *Annu. Rev. Immunol.* 9: 457-92 (1991); Capel *et al.*, *Immunomethods* 4: 25-34 (1994); and de Haas *et al.*, *J. Lab. Clin. Med.* 126: 330-41 (1995). Other FcRs, including those to be identified in the future, are encompassed by the term “FcR” herein.

[0055] The terms “CDR”, and its plural “CDRs”, refer to a complementarity determining region (CDR) of which three make up the binding character of a light chain variable region (CDRL1, CDRL2 and CDRL3) and three make up the binding character of a heavy chain variable region (CDRH1, CDRH2 and CDRH3). CDRs contribute to the functional activity of an antibody molecule and are separated by amino acid sequences that comprise scaffolding or framework regions. The exact definitional CDR boundaries and lengths are subject to different classification and numbering systems. CDRs may therefore be referred to by Kabat, Chothia, contact or any other boundary definitions, including the numbering system described herein. Despite differing boundaries, each of these systems has some degree of overlap in what constitutes the so called “hypervariable regions” within the variable sequences. CDR definitions according to these systems may therefore differ in length and boundary areas with respect to the

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adjacent framework region. See for example Kabat, Chothia, and/or MacCallum *et al.*, (Kabat *et al.*, in “Sequences of Proteins of Immunological Interest,” 5th Edition, U.S. Department of Health and Human Services, 1992; Chothia *et al.*, J. Mol. Biol., 1987, 196: 901; and MacCallum *et al.*, J. Mol. Biol., 1996, 262: 732).

5 [0056] As used herein, the term “antigen-binding portion” of an antibody (or simply “antibody portion”), refers to one or more fragments of an antibody that retain the ability to specifically bind to an antigen (*e.g.*, PD-1, PD-L1, and/or PD-L2). It has been shown that the antigen-binding function of an antibody can be performed by fragments of a full-length antibody. Examples of binding fragments encompassed within the term “antigen-binding portion” of an antibody include (i) a
10 Fab fragment, a monovalent fragment consisting of the V_H, V_L, CL and CH1 domains; (ii) a F(ab')₂ fragment, a bivalent fragment comprising two Fab fragments linked by a disulfide bridge at the hinge region; (iii) a Fd fragment consisting of the V_H and CH1 domains; (iv) a Fv fragment consisting of the V_H and V_L domains of a single arm of an antibody, (v) a dAb fragment (Ward *et al.*, (1989) Nature 341:544-546), which consists of a V_H domain; and (vi) an isolated complementarity determining
15 region (CDR) or (vii) a combination of two or more isolated CDRs which may optionally be joined by a synthetic linker. Furthermore, although the two domains of the Fv fragment, V_H and V_L, are coded for by separate genes, they can be joined, using recombinant methods, by a synthetic linker that enables them to be made as a single protein chain in which the V_H and V_L regions pair to form monovalent molecules (known as single chain Fv (scFv); see *e.g.*, Bird *et al.* (1988) Science 242:423-
20 426; and Huston *et al.* (1988) Proc. Natl. Acad. Sci. USA 85:5879-5883). Such single chain antibodies are also intended to be encompassed within the term “antigen-binding portion” of an antibody. These antibody fragments are obtained using conventional techniques known to those with skill in the art, and the fragments are screened for utility in the same manner as are intact antibodies.

[0057] Antibodies may be polyclonal or monoclonal; xenogeneic, allogeneic, or syngeneic; or
25 modified forms thereof (*e.g.*, humanized, chimeric, etc.). Antibodies may also be fully human. Preferably, antibodies of the invention bind specifically or substantially specifically to PD-1, PD-L1, or PD-L2 polypeptides. The term “monoclonal antibody” as used herein, refers to an antibody which displays a single binding specificity and affinity for a particular epitope. Accordingly, the term “human monoclonal antibody” refers to an antibody which displays a single binding specificity and
30 which has variable and constant regions derived from human germline or non-germline immunoglobulin sequences. In one embodiment, human monoclonal

antibodies are produced by a hybridoma which includes a B cell obtained from a transgenic non-human animal, *e.g.*, a transgenic mouse, having a genome comprising a human heavy chain transgene and a light chain transgene fused to an immortalized cell.

[0058] As used herein, the term an “isolated antibody” is intended to refer to an antibody which is substantially free of other antibodies having different antigenic specificities (*e.g.*, an isolated antibody that specifically binds to PD-1, PD-L1, or PD-L2 is substantially free of antibodies that do not bind to PD-1, PD-L1, or PD-L2, respectively). An isolated antibody that specifically binds to an epitope of PD-1, PD-L1, and/or PD-L2 may, however, have cross-reactivity to other PD-1, PD-L1, and/or PD-L2 proteins, respectively, from different species. However, the antibody preferably always binds to human PD-1, PD-L1, and/or PD-L2. In addition, an isolated antibody is typically substantially free of other cellular material and/or chemicals. In one embodiment of the invention, a combination of “isolated” monoclonal antibodies having different specificities to PD-1, PD-L1, and/or PD-L2 are combined in a well defined composition.

[0059] As used herein, the term “humanized antibody” refers to an antibody that consists of the CDR of antibodies derived from mammals other than human, and the FR region and the constant region of a human antibody. A humanized antibody is useful as an effective component in a therapeutic agent according to the present invention since antigenicity of the humanized antibody in human body is lowered.

[0060] As used herein, the term “composite antibody” refers to an antibody which has variable regions comprising germline or non-germline immunoglobulin sequences from two or more unrelated variable regions. Additionally, the term “composite, human antibody” refers to an antibody which has constant regions derived from human germline or non-germline immunoglobulin sequences and variable regions comprising human germline or non-germline sequences from two or more unrelated human variable regions. A composite, human antibody is useful as an effective component in a therapeutic agent according to the present invention since the antigenicity of the composite, human antibody in human body is lowered.

[0061] As used herein, the term “recombinant human antibody” includes all human antibodies that are prepared, expressed, created or isolated by recombinant means, such as (a) antibodies isolated from an animal (*e.g.*, a mouse) that is transgenic or transchromosomal for human immunoglobulin genes or a hybridoma prepared therefrom (described further in Section I, below), (b) antibodies isolated from a host cell transformed to express the antibody, *e.g.*, from a

transfectoma, (c) antibodies isolated from a recombinant, combinatorial human antibody library, and (d) antibodies prepared, expressed, created or isolated by any other means that involve splicing of human immunoglobulin gene sequences to other DNA sequences. Such recombinant human antibodies have variable and constant regions derived from human germline and/or non-germline immunoglobulin sequences. In certain embodiments, however, such recombinant human antibodies can be subjected to *in vitro* mutagenesis (or, when an animal transgenic for human Ig sequences is used, *in vivo* somatic mutagenesis) and thus the amino acid sequences of the V_H and V_L regions of the recombinant antibodies are sequences that, while derived from and related to human germline V_H and V_L sequences, may not naturally exist within the human antibody germline repertoire *in vivo*.

[0062] As used herein, the term “heterologous antibody” is defined in relation to the transgenic non-human organism producing such an antibody. This term refers to an antibody having an amino acid sequence or an encoding nucleic acid sequence corresponding to that found in an organism not consisting of the transgenic non-human animal, and generally from a species other than that of the transgenic non-human animal.

[0063] As used herein, the term “K_D” is intended to refer to the dissociation equilibrium constant of a particular antibody-antigen interaction.

[0064] As used herein, the term “specific binding” refers to antibody binding to a predetermined antigen. Typically, the antibody binds with an affinity (K_D) of approximately less than 10⁻⁷ M, such as approximately less than 10⁻⁸ M, 10⁻⁹ M or 10⁻¹⁰ M or even lower when determined by surface plasmon resonance (SPR) technology in a BIACORE 3000 instrument using recombinant human PD-1, PD-L1, or PD-L2 as the analyte and the antibody as the ligand, and binds to the predetermined antigen with an affinity that is at least 1.1-, 1.2-, 1.3-, 1.4-, 1.5-, 1.6-, 1.7-, 1.8-, 1.9-, 2.0-, 2.5-, 3.0-, 3.5-, 4.0-, 4.5-, 5.0-, 6.0-, 7.0-, 8.0-, 9.0-, or 10.0-fold or greater than its affinity for binding to a non-specific antigen (*e.g.*, BSA, casein) other than the predetermined antigen or a closely-related antigen. The phrases “an antibody recognizing an antigen” and “an antibody specific for an antigen” are used interchangeably herein with the term “an antibody which binds specifically to an antigen”.

[0065] As used herein, the term “isotype” refers to the antibody class (*e.g.*, IgM or IgG1) that is encoded by heavy chain constant region genes.

[0066] As used herein, the term “glycosylation pattern” is defined as the pattern of carbohydrate units that are covalently attached to a protein, more specifically to an

immunoglobulin protein. A glycosylation pattern of a heterologous antibody can be characterized as being substantially similar to glycosylation patterns which occur naturally on antibodies produced by the species of the nonhuman transgenic animal, when one of ordinary skill in the art would recognize the glycosylation pattern of the heterologous antibody as being more similar to said pattern of glycosylation in the species of the nonhuman transgenic animal than to the species from which the CH genes of the transgene were derived.

[0067] As used herein, the term “naturally-occurring” as applied to an object refers to the fact that an object can be found in nature. For example, a polypeptide or polynucleotide sequence that is present in an organism (including viruses) that can be isolated from a source in nature and which has not been intentionally modified by man in the laboratory is naturally-occurring.

[0068] As used herein, the term “rearranged” refers to a configuration of a heavy chain or light chain immunoglobulin locus wherein a V segment is positioned immediately adjacent to a D-J or J segment in a conformation encoding essentially a complete V_H and V_L domain, respectively. A rearranged immunoglobulin gene locus can be identified by comparison to germline DNA; a rearranged locus will have at least one recombined heptamer/nonamer homology element.

[0069] As used herein, the term “unrearranged” or “germline configuration” in reference to a V segment refers to the configuration wherein the V segment is not recombined so as to be immediately adjacent to a D or J segment.

[0070] As used herein, the term “nucleic acid molecule” is intended to include DNA molecules and RNA molecules. A nucleic acid molecule may be single-stranded or double-stranded, but preferably is double-stranded DNA.

[0071] As used herein, the term “isolated nucleic acid molecule” in reference to nucleic acids encoding antibodies or antibody portions (*e.g.*, V_H , V_L , CDR3) that bind to PD-1, PD-L1, or PD-L2, is intended to refer to a nucleic acid molecule in which the nucleotide sequences encoding the antibody or antibody portion are free of other nucleotide sequences encoding antibodies or antibody portions that bind antigens other than PD-1, PD-L1, or PD-L2, respectively, which other sequences may naturally flank the nucleic acid in human genomic DNA. Figures 2-7 correspond to the nucleotide and amino acid sequences comprising the heavy chain (V_H) and light chain (V_L) variable regions of the human anti-PD-1, PD-L1, or PD-L2 antibodies of the present invention, respectively.

[0072] The present invention also encompasses “conservative sequence modifications” of the sequences set forth in the figures (*e.g.*, Figures 2-7), including nucleotide and amino acid

sequence modifications which do not significantly affect or alter the binding characteristics of the antibody encoded by the nucleotide sequence or containing the amino acid sequence. Such conservative sequence modifications include nucleotide and amino acid substitutions, additions and deletions. Modifications can be introduced into the sequence set forth in the figures (*e.g.*, Figures 2-7) by standard techniques known in the art, such as site-directed mutagenesis and PCR-mediated mutagenesis. Conservative amino acid substitutions include ones in which the amino acid residue is replaced with an amino acid residue having a similar side chain. Families of amino acid residues having similar side chains have been defined in the art. These families include amino acids with basic side chains (*e.g.*, lysine, arginine, histidine), acidic side chains (*e.g.*, aspartic acid, glutamic acid), uncharged polar side chains (*e.g.*, glycine, asparagine, glutamine, serine, threonine, tyrosine, cysteine, tryptophan), nonpolar side chains (*e.g.*, alanine, valine, leucine, isoleucine, proline, phenylalanine, methionine), beta-branched side chains (*e.g.*, threonine, valine, isoleucine) and aromatic side chains (*e.g.*, tyrosine, phenylalanine, tryptophan, histidine). Thus, a predicted nonessential amino acid residue in a human anti-PD-1, anti-PD-L1, or anti-PD-L2 antibody is preferably replaced with another amino acid residue from the same side chain family.

[0073] Alternatively, in another embodiment, mutations can be introduced randomly along all or part of a human anti-PD-1, PD-L1, or PD-L2 antibody coding sequence, such as by saturation mutagenesis, and the resulting modified human anti-PD-1, anti-PD-L1, or anti-PD-L2 antibodies can be screened for binding activity.

[0074] Accordingly, antibodies encoded by the heavy and light chain variable region nucleotide sequences disclosed herein and/or containing the heavy and light chain variable region amino acid sequences disclosed herein (*e.g.*, Figures 2-7) include substantially similar antibodies encoded by or containing similar sequences which have been conservatively modified. Further discussion as to how such substantially similar antibodies can be generated based on the sequences (*i.e.*, heavy and light chain variable regions) disclosed herein (*e.g.*, Figures 2-7) is provided below.

[0075] In addition, there is a known and definite correspondence between the amino acid sequence of a particular protein and the nucleotide sequences that can code for the protein, as defined by the genetic code (shown below). Likewise, there is a known and definite correspondence between the nucleotide sequence of a particular nucleic acid and the amino acid sequence encoded by that nucleic acid, as defined by the genetic code.

GENETIC CODE

Alanine (Ala, A)	GCA, GCC, GCG, GCT
Arginine (Arg, R)	AGA, ACG, CGA, CGC, CGG, CGT
Asparagine (Asn, N)	AAC, AAT
Aspartic acid (Asp, D)	GAC, GAT
Cysteine (Cys, C)	TGC, TGT
Glutamic acid (Glu, E)	GAA, GAG
Glutamine (Gln, Q)	CAA, CAG
Glycine (Gly, G)	GGA, GGC, GGG, GGT
Histidine (His, H)	CAC, CAT
Isoleucine (Ile, I)	ATA, ATC, ATT
Leucine (Leu, L)	CTA, CTC, CTG, CTT, TTA, TTG
Lysine (Lys, K)	AAA, AAG
Methionine (Met, M)	ATG
Phenylalanine (Phe, F)	TTC, TTT
Proline (Pro, P)	CCA, CCC, CCG, CCT
Serine (Ser, S)	AGC, AGT, TCA, TCC, TCG, TCT
Threonine (Thr, T)	ACA, ACC, ACG, ACT
Tryptophan (Trp, W)	TGG
Tyrosine (Tyr, Y)	TAC, TAT
Valine (Val, V)	GTA, GTC, GTG, GTT
Termination signal (end)	TAA, TAG, TGA

[0076] An important and well known feature of the genetic code is its redundancy, whereby, for most of the amino acids used to make proteins, more than one coding nucleotide triplet may be employed (illustrated above). Therefore, a number of different nucleotide sequences may code for a given amino acid sequence. Such nucleotide sequences are considered functionally equivalent since they result in the production of the same amino acid sequence in all organisms (although certain organisms may translate some sequences more efficiently than they do others). Moreover, occasionally, a methylated variant of a purine or pyrimidine may be found in a given nucleotide sequence. Such methylations do not affect the coding relationship between the trinucleotide codon and the corresponding amino acid.

[0077] For nucleic acids, the term “substantial homology” indicates that two nucleic acids, or designated sequences thereof, when optimally aligned and compared, are identical, with appropriate nucleotide insertions or deletions, in at least about 80% of the nucleotides, usually at least about 90%, 91%, 92%, 93%, 94%, 95%, 96%, or more of the nucleotides, and more preferably at least about 97%, 98%, 99% or more of the nucleotides. Alternatively, substantial homology exists when the segments will hybridize under selective hybridization conditions, to the complement of the strand.

[0078] The percent identity between two sequences is a function of the number of identical positions shared by the sequences (*i.e.*, % identity= # of identical positions/total # of positions x 100), taking into account the number of gaps, and the length of each gap, which need to be introduced for optimal alignment of the two sequences. The comparison of sequences and determination of percent identity between two sequences can be accomplished using a mathematical algorithm, as described in the non-limiting examples below.

[0079] The percent identity between two nucleotide sequences can be determined using the GAP program in the GCG software package (available on the world wide web at the GCG company website), using a NWSgapdna.CMP matrix and a gap weight of 40, 50, 60, 70, or 80 and a length weight of 1, 2, 3, 4, 5, or 6. The percent identity between two nucleotide or amino acid sequences can also be determined using the algorithm of E. Meyers and W. Miller (CABIOS, 4:11 17 (1989)) which has been incorporated into the ALIGN program (version 2.0), using a PAM120 weight residue table, a gap length penalty of 12 and a gap penalty of 4. In addition, the percent identity between two amino acid sequences can be determined using the Needleman and Wunsch (J. Mol. Biol. (48):444 453 (1970)) algorithm which has been incorporated into the GAP program in the GCG software package (available on the world wide web at the GCG company website), using either a Blosum 62 matrix or a PAM250 matrix, and a gap weight of 16, 14, 12, 10, 8, 6, or 4 and a length weight of 1, 2, 3, 4, 5, or 6.

[0080] The nucleic acid and protein sequences of the present invention can further be used as a “query sequence” to perform a search against public databases to, for example, identify related sequences. Such searches can be performed using the NBLAST and XBLAST programs (version 2.0) of Altschul, *et al.* (1990) J. Mol. Biol. 215:403 10. BLAST nucleotide searches can be performed with the NBLAST program, score=100, wordlength=12 to obtain nucleotide sequences homologous to the nucleic acid molecules of the invention. BLAST protein searches can be performed with the XBLAST program, score=50, wordlength=3 to obtain amino acid

sequences homologous to the protein molecules of the invention. To obtain gapped alignments for comparison purposes, Gapped BLAST can be utilized as described in Altschul *et al.*, (1997) Nucleic Acids Res. 25(17):3389 3402. When utilizing BLAST and Gapped BLAST programs, the default parameters of the respective programs (*e.g.*, XBLAST and NBLAST) can be used (available on the world wide web at the NCBI website).

[0081] The nucleic acids may be present in whole cells, in a cell lysate, or in a partially purified or substantially pure form. A nucleic acid is “isolated” or “rendered substantially pure” when purified away from other cellular components or other contaminants, *e.g.*, other cellular nucleic acids or proteins, by standard techniques, including alkaline/SDS treatment, CsCl banding, column chromatography, agarose gel electrophoresis and others well known in the art. See, F. Ausubel, *et al.*, ed. Current Protocols in Molecular Biology, Greene Publishing and Wiley Interscience, New York (1987).

[0082] The nucleic acid compositions of the present invention, while often in a native sequence (except for modified restriction sites and the like), from either cDNA, genomic or mixtures thereof may be mutated, in accordance with standard techniques to provide gene sequences. For coding sequences, these mutations, may affect amino acid sequence as desired. In particular, DNA sequences substantially homologous to or derived from native V, D, J, constant, switches and other such sequences described herein are contemplated (where “derived” indicates that a sequence is identical or modified from another sequence).

[0083] A nucleic acid is “operably linked” when it is placed into a functional relationship with another nucleic acid sequence. For instance, a promoter or enhancer is operably linked to a coding sequence if it affects the transcription of the sequence. With respect to transcription regulatory sequences, operably linked means that the DNA sequences being linked are contiguous and, where necessary to join two protein coding regions, contiguous and in reading frame. For switch sequences, operably linked indicates that the sequences are capable of effecting switch recombination.

[0084] As used herein, the term “vector” is intended to refer to a nucleic acid molecule capable of transporting another nucleic acid to which it has been linked. One type of vector is a “plasmid”, which refers to a circular double stranded DNA loop into which additional DNA segments may be ligated. Another type of vector is a viral vector, wherein additional DNA segments may be ligated into the viral genome. Certain vectors are capable of autonomous replication in a host cell into which they are introduced (*e.g.*, bacterial vectors having a bacterial

origin of replication and episomal mammalian vectors). Other vectors (*e.g.*, non-episomal mammalian vectors) can be integrated into the genome of a host cell upon introduction into the host cell, and thereby are replicated along with the host genome. Moreover, certain vectors are capable of directing the expression of genes to which they are operatively linked. Such vectors are referred to herein as “recombinant expression vectors” (or simply, “expression vectors”). In general, expression vectors of utility in recombinant DNA techniques are often in the form of plasmids. In the present specification, “plasmid” and “vector” may be used interchangeably as the plasmid is the most commonly used form of vector. However, the invention is intended to include such other forms of expression vectors, such as viral vectors (*e.g.*, replication defective retroviruses, adenoviruses and adeno-associated viruses), which serve equivalent functions.

[0085] As used herein, the term “recombinant host cell” (or simply “host cell”), is intended to refer to a cell into which a recombinant expression vector has been introduced. It should be understood that such terms are intended to refer not only to the particular subject cell but to the progeny of such a cell. Because certain modifications may occur in succeeding generations due to either mutation or environmental influences, such progeny may not, in fact, be identical to the parent cell, but are still included within the scope of the term “host cell” as used herein.

[0086] As used herein, the term “subject” includes any human or non-human animal. For example, the methods and compositions of the present invention can be used to treat a subject with an inflammatory disease, such as arthritis, *e.g.*, rheumatoid arthritis. The term “non-human animal” includes all vertebrates, *e.g.*, mammals and non-mammals, such as non-human primates, sheep, dog, cow, chickens, amphibians, reptiles, etc.

[0087] As used herein, the term “modulate” includes up-regulation and down-regulation, *e.g.*, enhancing or inhibiting a response.

[0088] As used herein, the term “inhibit” includes the decrease, limitation, or blockage, of, for example a particular action, function, or interaction.

[0089] As used herein, the term “immune cell” refers to cells that play a role in the immune response. Immune cells are of hematopoietic origin, and include lymphocytes, such as B cells and T cells; natural killer cells; myeloid cells, such as monocytes, macrophages, eosinophils, mast cells, basophils, and granulocytes.

[0090] As used herein, the term “T cell” includes CD4⁺ T cells and CD8⁺ T cells. The term T cell also includes T helper 1 type T cells, T helper 2 type T cells, T helper 17 type T cells and inhibitory T cells. The term “antigen presenting cell” includes professional antigen presenting

cells (*e.g.*, B lymphocytes, monocytes, dendritic cells, Langerhans cells) as well as other antigen presenting cells (*e.g.*, keratinocytes, endothelial cells, astrocytes, fibroblasts, oligodendrocytes).

[0091] As used herein, the term “immune response” includes T cell mediated and/or B cell mediated immune responses that are influenced by modulation of T cell costimulation.

Exemplary immune responses include T cell responses, *e.g.*, cytokine production, and cellular cytotoxicity. In addition, the term immune response includes immune responses that are indirectly affected by T cell activation, *e.g.*, antibody production (humoral responses) and activation of cytokine responsive cells, *e.g.*, macrophages.

[0092] As used herein, the term “costimulate,” as used with reference to activated immune cells, includes the ability of a costimulatory polypeptide to provide a second, non-activating receptor mediated signal (a “costimulatory signal”) that induces proliferation and/or effector function. For example, a costimulatory signal can result in cytokine secretion, *e.g.*, in a T cell that has received a T cell-receptor-mediated signal. Immune cells that have received a cell-receptor mediated signal, *e.g.*, via an activating receptor are referred to herein as “activated immune cells.”

[0093] As used herein, the term “inhibitory signal” refers to a signal transmitted via an inhibitory receptor (*e.g.*, CTLA4 or PD-1) for a polypeptide on an immune cell. Such a signal antagonizes a signal via an activating receptor (*e.g.*, via a TCR or CD3 polypeptide) and can result in, *e.g.*, inhibition of second messenger generation; an inhibition of proliferation; an inhibition of effector function in the immune cell, *e.g.*, reduced phagocytosis, reduced antibody production, reduced cellular cytotoxicity, the failure of the immune cell to produce mediators, (such as cytokines (*e.g.*, IL-2) and/or mediators of allergic responses); or the development of anergy.

[0094] As used herein, the term “unresponsiveness” includes refractivity of immune cells to stimulation, *e.g.*, stimulation via an activating receptor or a cytokine. Unresponsiveness can occur, *e.g.*, because of exposure to immunosuppressants or exposure to high doses of antigen. As used herein, the term “anergy” or “tolerance” includes refractivity to activating receptor-mediated stimulation. Such refractivity is generally antigen-specific and persists after exposure to the tolerizing antigen has ceased. For example, anergy in T cells (as opposed to unresponsiveness) is characterized by lack of cytokine production, *e.g.*, IL-2. T cell anergy occurs when T cells are exposed to antigen and receive a first signal (a T cell receptor or CD-3 mediated signal) in the absence of a second signal (a costimulatory signal). Under these

conditions, reexposure of the cells to the same antigen (even if reexposure occurs in the presence of a costimulatory polypeptide) results in failure to produce cytokines and, thus, failure to proliferate. Anergic T cells can, however, proliferate if cultured with cytokines (*e.g.*, IL-2). For example, T cell anergy can also be observed by the lack of IL-2 production by T lymphocytes as measured by ELISA or by a proliferation assay using an indicator cell line. Alternatively, a reporter gene construct can be used. For example, anergic T cells fail to initiate IL-2 gene transcription induced by a heterologous promoter under the control of the 5' IL-2 gene enhancer or by a multimer of the AP1 sequence that can be found within the enhancer (Kang *et al.* (1992) *Science* 257:1134).

[0095] As used herein, the term “activity,” when used with respect to a polypeptide, *e.g.*, PD-1, PD-L1, or PD-L2 polypeptide, includes activities which are inherent in the structure of the protein. For example, with regard to PD-1 ligand, the term “activity” includes the ability to modulate immune cell costimulation (*e.g.* by modulating a costimulatory signal in an activated immune cell) or to modulate inhibition by modulating an inhibitory signal in an immune cell (*e.g.*, by engaging a natural receptor on an immune cell). Those of skill in the art will recognize that when a PD-1 ligand polypeptide binds to a costimulatory receptor, a costimulatory signal can be generated in the immune cell. When a PD-1 ligand polypeptide binds to an inhibitory receptor, an inhibitory signal is generated in the immune cell. Also, when a PD-1 ligand binds to a B7-1 polypeptide, an inhibitory signal can be generated (Butte *et al.* (2007) *Immunity* 27:111).

[0096] With respect to PD-1, the term “activity” includes the ability of a PD-1 polypeptide to modulate an inhibitory signal in an immune cell, *e.g.*, by engaging a natural PD-1 ligand on an antigen presenting cell. PD-1 transmits an inhibitory signal to an immune cell in a manner similar to CTLA4. Modulation of an inhibitory signal in an immune cell results in modulation of proliferation of, and/or cytokine secretion by, an immune cell. Thus, the term “PD-1 activity” includes the ability of a PD-1 polypeptide to bind its natural ligand(s), the ability to modulate immune cell costimulatory or inhibitory signals, and the ability to modulate the immune response.

[0097] As used herein, the term “interaction”, when referring to an interaction between two molecules, refers to the physical contact (*e.g.*, binding) of the molecules with one another. Generally, such an interaction results in an activity (which produces a biological effect) of one or both of said molecules. The activity may be a direct activity of one or both of the molecules,

(*e.g.*, signal transduction). Alternatively, one or both molecules in the interaction may be prevented from binding a ligand, and thus be held inactive with respect to ligand binding activity (*e.g.*, binding its ligand and triggering or inhibiting costimulation). To inhibit such an interaction results in the disruption of the activity of one or more molecules involved in the interaction. To enhance such an interaction is to prolong or increase the likelihood of said physical contact, and prolong or increase the likelihood of said activity.

[0098] As used herein the singular forms “a”, “an”, and “the” include plural referents unless the context clearly dictates otherwise.

[0099] It is understood that aspects and embodiments of the invention described herein include “consisting” and/or “consisting essentially of” aspects and embodiments.

[0100] Various aspects of the invention are described in further detail in the following subsections.

I. Isolated Nucleic Acid Molecules

[0101] One aspect of the invention pertains to isolated nucleic acid molecules that encode polypeptides of the present invention (*e.g.*, those in Figures 2-7) or biologically active portions thereof, as well as nucleic acid fragments sufficient for use as hybridization probes to identify nucleic acid molecules encoding these polypeptides and fragments for use as PCR primers for the amplification or mutation of the nucleic acid molecules. As used herein, the term “nucleic acid molecule” is intended to include DNA molecules (*e.g.*, cDNA or genomic DNA) and RNA molecules (*e.g.*, mRNA) and analogs of the DNA or RNA generated using nucleotide analogs. The nucleic acid molecule can be single-stranded or double-stranded, but preferably is double-stranded DNA.

[0102] The term “isolated nucleic acid molecule” includes nucleic acid molecules which are separated from other nucleic acid molecules which are present in the natural source of the nucleic acid. For example, with regards to genomic DNA, the term “isolated” includes nucleic acid molecules which are separated from the chromosome with which the genomic DNA is naturally associated. Preferably, an “isolated” nucleic acid molecule is free of sequences which naturally flank the nucleic acid (*i.e.*, sequences located at the 5’ and 3’ ends of the nucleic acid molecule) in the genomic DNA of the organism from which the nucleic acid is derived. For example, an “isolated” nucleic acid molecule, such as a cDNA molecule, can be substantially

free of other cellular material, or culture medium, when produced by recombinant techniques, or substantially free of chemical precursors or other chemicals when chemically synthesized.

[0103] A nucleic acid molecule of the present invention (*e.g.*, those in Figures 2-7), or a portion thereof, can be isolated using standard molecular biology techniques and the sequence information provided herein. For example, a nucleic acid molecule encompassing all or a portion of sequences shown in Figures 2-7 can be isolated by the polymerase chain reaction (PCR) using synthetic oligonucleotide primers designed based upon the sequences shown in Figures 2-7.

[0104] A nucleic acid molecule of the invention can be amplified using cDNA, mRNA or, alternatively, genomic DNA as a template and appropriate oligonucleotide primers according to standard PCR amplification techniques. The nucleic acid molecule so amplified can be cloned into an appropriate vector and characterized by DNA sequence analysis. Furthermore, oligonucleotides corresponding to nucleic acid sequences of the invention can be prepared by standard synthetic techniques, *e.g.*, using an automated DNA synthesizer.

[0105] In another embodiment, an isolated nucleic acid molecule of the invention comprises a nucleic acid molecule which is a complement of a nucleic acid molecule of the present invention (*e.g.*, those in Figures 2-7), or a portion thereof. A nucleic acid molecule which is complementary to a nucleic acid molecule of the present invention (*e.g.*, those in Figures 2-7), or a portion thereof, is one which is sufficiently complementary to the nucleotide sequence shown in Figures 2-7, such that it can hybridize to the respective nucleotide sequence shown in Figures 2-7, thereby forming a stable duplex.

[0106] In still another embodiment, an isolated nucleic acid molecule of the present invention comprises a nucleotide sequence which is at least about 70%, 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% or more identical to the entire length of the nucleotide sequence shown in Figures 2-7, or a portion of any of these nucleotide sequences.

[0107] Moreover, the nucleic acid molecule of the invention can comprise only a portion of a nucleic acid molecule of the present invention (*e.g.*, those in Figures 2-7), or a portion thereof, for example, a fragment which can be used as a probe or primer or a fragment which encodes a portion of a polypeptide of the invention, *e.g.*, those in Figures 2-7. The probe/primer typically comprises substantially purified oligonucleotide. The oligonucleotide typically comprises a region of nucleotide sequence that hybridizes under stringent conditions to at least about 12 or 15, preferably about 20 or 25, more preferably about 30, 35, 40, 45, 50, 55, 60, 65, or 75

consecutive nucleotides of a nucleic acid molecule of the present invention (*e.g.*, those in Figures 2-7); of an anti-sense sequence of a nucleic acid molecule of the present invention (*e.g.*, those in Figures 2-7); or of a mutant of a nucleic acid molecule of the present invention (*e.g.*, those in Figures 2-7).

[0108] Probes based on a nucleic acid molecule of the present invention (*e.g.*, those in Figures 2-7) can be used to detect transcripts or genomic sequences encoding the same or homologous polypeptides. In one embodiment, the probe further comprises a label group attached thereto, *e.g.*, the label group can be a radioisotope, a fluorescent compound, an enzyme, or an enzyme co-factor.

[0109] A nucleic acid fragment encoding a “biologically active portion of a polypeptide of the invention” can be prepared by isolating a portion of the nucleotide sequence of a nucleic acid molecule of the present invention (*e.g.*, those in Figures 2-7) which encodes a polypeptide having a biological activity of a polypeptide of the invention (*e.g.*, the ability to bind to its antigenic target), expressing the encoded portion of the polypeptide of the invention (*e.g.*, by recombinant expression *in vitro*) and assessing the activity of the encoded portion of the polypeptide of the invention.

[0110] The invention further encompasses nucleic acid molecules that differ from nucleotide sequence(s) shown in Figures 2-7 due to degeneracy of the genetic code and thus encode the same polypeptides as those encoded by the respective nucleotide sequence shown in Figures 2-7. In another embodiment, an isolated nucleic acid molecule of the invention has a nucleotide sequence encoding a polypeptide of the present invention (*e.g.*, those in Figures 2-7).

[0111] Nucleic acid molecules corresponding to homologues of a nucleic acid molecule of the present invention (*e.g.*, those in Figures 2-7) can be isolated based on their homology to the nucleic acids disclosed herein using the cDNAs disclosed herein, or a portion thereof, as a hybridization probe according to standard hybridization techniques under stringent hybridization conditions.

[0112] Accordingly, in another embodiment, an isolated nucleic acid molecule of the invention is at least 15, 20, 25, 30 or more nucleotides in length and hybridizes under stringent conditions to the nucleic acid molecule comprising a nucleic acid molecule of the present invention (*e.g.*, those in Figures 2-7).

[0113] As used herein, the term “hybridizes under stringent conditions” is intended to describe conditions for hybridization and washing under which nucleotide sequences that are significantly

identical or homologous to each other remain hybridized to each other. Preferably, the conditions are such that sequences at least about 70%, more preferably at least about 80%, even more preferably at least about 85% or 90% identical to each other remain hybridized to each other. Such stringent conditions are known to those skilled in the art and can be found in Current Protocols in Molecular Biology, Ausubel et al., eds., John Wiley & Sons, Inc. (1995), sections 2, 4 and 6. Additional stringent conditions can be found in Molecular Cloning: A Laboratory Manual, Sambrook et al., Cold Spring Harbor Press, Cold Spring Harbor, N.Y. (1989), chapters 7, 9 and 11. A non-limiting example of stringent hybridization conditions includes hybridization in 4x or 6x sodium chloride/sodium citrate (SSC), at about 65-70°C (or hybridization in 4x SSC plus 50% formamide at about 42-50°C) followed by one or more washes in 1x SSC, at about 65-70°C. A further non-limiting example of stringent hybridization conditions includes hybridization at 6x SSC at 45°C, followed by one or more washes in 0.2x SSC, 0.1% SDS at 65°C. A non-limiting example of highly stringent hybridization conditions includes hybridization in 1x SSC, at about 65-70°C (or hybridization in 1x SSC plus 50% formamide at about 42-50°C) followed by one or more washes in 0.3x SSC, at about 65-70°C. A non-limiting example of reduced stringency hybridization conditions includes hybridization in 4x or 6x SSC, at about 50-60°C (or alternatively hybridization in 6x SSC plus 50% formamide at about 40-45°C) followed by one or more washes in 2x, at about 50-60°C. Ranges intermediate to the above-recited values, *e.g.*, at 65-70°C or at 42-50°C are also intended to be encompassed by the present invention. SSPE (1x SSPE is 0.15M NaCl, 10mM NaH₂PO₄, and 1.25 mM EDTA, pH 7.4) can be substituted for SSC (1x SSC is 0.15M NaCl and 15mM sodium citrate) in the hybridization and wash buffers; washes are performed for 15 minutes each after hybridization is complete. The hybridization temperature for hybrids anticipated to be less than 50 base pairs in length should be 5-10°C less than the melting temperature (T_m) of the hybrid, where T_m is determined according to the following equations. For hybrids less than 18 base pairs in length, T_m (°C) = 2(# of A + T bases) + 4(# of G + C bases). For hybrids between 18 and 49 base pairs in length, T_m (°C) = 81.5 + 16.6(log₁₀[Na⁺]) + 0.41(%G+C) - (600/N), where N is the number of bases in the hybrid, and [Na⁺] is the concentration of sodium ions in the hybridization buffer ([Na⁺] for 1x SSC = 0.165 M). It will also be recognized by the skilled practitioner that additional reagents may be added to hybridization and/or wash buffers to decrease non-specific hybridization of nucleic acid molecules to membranes, for example, nitrocellulose or nylon

membranes, including but not limited to blocking agents (*e.g.*, BSA or salmon or herring sperm carrier DNA), detergents (*e.g.*, SDS), chelating agents (*e.g.*, EDTA), Ficoll, PVP and the like. When using nylon membranes, in particular, an additional non-limiting example of stringent hybridization conditions is hybridization in 0.25-0.5M NaH₂PO₄, 7% SDS at about 65°C, followed by one or more washes at 0.02M NaH₂PO₄, 1% SDS at 65°C, see *e.g.*, Church and Gilbert (1984) Proc. Natl. Acad. Sci. USA 81:1991-1995 (or alternatively 0.2x SSC, 1% SDS).

[0114] The skilled artisan will further appreciate that changes can be introduced by mutation into a nucleic acid molecule of the present invention (*e.g.*, those in Figures 2-7), thereby leading to changes in the amino acid sequence of the encoded polypeptides of the present invention, without altering the functional ability of the polypeptides. For example, nucleotide substitutions leading to amino acid substitutions at “non-essential” amino acid residues can be made in a nucleic acid molecule of the present invention (*e.g.*, those in Figures 2-7). A “non-essential” amino acid residue is a residue that can be altered from a nucleic acid molecule of the present invention (*e.g.*, those in Figures 2-7) without altering the biological activity, whereas an “essential” amino acid residue is required for biological activity. For example, amino acid residues that are conserved among the polypeptides of the present invention, *e.g.*, those required for binding of the polypeptides to its target antigen, are predicted to be particularly unamenable to alteration.

[0115] Accordingly, another aspect of the invention pertains to nucleic acid molecules encoding polypeptides of the present invention (*e.g.*, those in Figures 2-7) that contain changes in amino acid residues that are not essential for activity. Such polypeptides differ in amino acid sequence from those in Figures 2-7, yet retain biological activity. In one embodiment, the isolated nucleic acid molecule comprises a nucleotide sequence encoding a polypeptide, wherein the polypeptide comprises an amino acid sequence at least about 71%, 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% or more identical to those in Figures 2-7.

[0116] An isolated nucleic acid molecule encoding a polypeptide identical to the polypeptides of those in Figures 2-7 can be created by introducing one or more nucleotide substitutions, additions or deletions into the nucleotide sequence of those in Figures 2-7 such that one or more amino acid substitutions, additions or deletions are introduced into the encoded polypeptide. Mutations can be introduced into nucleic acid molecules of the present invention (*e.g.*, those in Figures 2-7) by standard techniques, such as site-directed mutagenesis and PCR-mediated mutagenesis. In one embodiment, conservative amino acid substitutions are made at one or

more predicted non-essential amino acid residues. A “conservative amino acid substitution” is one in which the amino acid residue is replaced with an amino acid residue having a similar side chain. Families of amino acid residues having similar side chains have been defined in the art. These families include amino acids with basic side chains (*e.g.*, lysine, arginine, histidine), acidic side chains (*e.g.*, aspartic acid, glutamic acid), uncharged polar side chains (*e.g.*, asparagine, glutamine, serine, threonine, tyrosine, cysteine), nonpolar side chains (*e.g.*, glycine, alanine, valine, leucine, isoleucine, proline, phenylalanine, methionine, tryptophan), beta-branched side chains (*e.g.*, threonine, valine, isoleucine) and aromatic side chains (*e.g.*, tyrosine, phenylalanine, tryptophan, histidine). Thus, a predicted nonessential amino acid residue in a polypeptide of the invention (*e.g.*, those in Figures 2-7) can be replaced with another amino acid residue from the same side chain family. Alternatively, in another embodiment, mutations can be introduced randomly along all or part of a nucleic acid molecule(s) of the present invention (*e.g.*, those in Figures 2-7), such as by saturation mutagenesis, and the resultant mutants can be screened for biological activity to identify mutants that retain activity. Following mutagenesis of a nucleic acid molecule of the present invention (*e.g.*, those in Figures 2-7), the encoded polypeptide can be expressed recombinantly and the activity of the polypeptide can be determined.

[0117] In one embodiment, a mutant polypeptide of the invention can be assayed for the ability to bind to and/or modulate the activity of a natural PD-1 (*e.g.*, PD-1 ligands) or PD-1 ligand partner (*e.g.*, PD-1 and B7-1), modulate intra- or intercellular signaling, modulate activation of T lymphocytes, and/or modulate the immune response of an organism.

[0118] Yet another aspect of the invention pertains to isolated nucleic acid molecules encoding fusion proteins. Such nucleic acid molecules, comprising at least a first nucleotide sequence encoding a polypeptide of the invention (*e.g.*, those in Figures 2-7) operatively linked to a second nucleotide sequence encoding a polypeptide of the invention (*e.g.*, those in Figures 2-7) can be prepared by standard recombinant DNA techniques.

[0119] The expression characteristics of a nucleic acid molecules of the present invention (*e.g.*, those in Figures 2-7) within a cell line or microorganism may be modified by inserting a heterologous DNA regulatory element into the genome of a stable cell line or cloned microorganism such that the inserted regulatory element is operatively linked with the a nucleic acid molecules of the present invention (*e.g.*, those in Figures 2-7). For example, a heterologous regulatory element may be inserted into a stable cell line or cloned microorganism, such that it is

operatively linked with a nucleic acid molecules of the present invention (*e.g.*, those in Figures 2-7), using techniques, such as targeted homologous recombination, which are well known to those of skill in the art, and described, *e.g.*, in Chappel, U.S. Pat. No. 5,272,071; PCT publication No. WO 91/06667, published May 16, 1991.

II. Isolated Polypeptide Molecules

[0120] One aspect of the invention pertains to isolated polypeptides of the present invention (including antibodies and antigen-binding fragments thereof described herein, and those in Figures 2-7), and biologically active portions thereof. In one embodiment, polypeptides of the present invention (*e.g.*, those in Figures 2-7), and biologically active portions thereof can be isolated from cells or tissue sources by an appropriate purification scheme using standard protein purification techniques. In another embodiment, polypeptides of the present invention (*e.g.*, those in Figures 2-7), and biologically active portions thereof are produced by recombinant DNA techniques. Alternatively, polypeptides of the present invention (*e.g.*, those in Figures 2-7), and biologically active portions thereof can be chemically synthesized using standard peptide synthesis techniques.

[0121] An “isolated” or “purified” polypeptide or biologically active portion thereof is substantially free of cellular material or other contaminating proteins from the cell or tissue source from which the polypeptides of the present invention (*e.g.*, those in Figures 2-7) is derived, or substantially free from chemical precursors or other chemicals when chemically synthesized. The language “substantially free of cellular material” includes preparations of polypeptide(s) of the present invention (*e.g.*, those in Figures 2-7), and biologically active portions thereof, in which the polypeptide is separated from cellular components of the cells from which it is isolated or recombinantly produced. In one embodiment, the language “substantially free of cellular material” includes preparations of polypeptide(s) of the present invention (*e.g.*, those in Figures 2-7), and biologically active portions thereof having less than about 30% (by dry weight) of proteins not of the present invention (also referred to herein as a “contaminating protein”), more preferably less than about 20% of proteins not of the present invention, still more preferably less than about 10% of proteins not of the present invention, and most preferably less than about 5% of proteins not of the present invention. When polypeptides of the present invention (*e.g.*, those in Figures 2-7) or biologically active portion thereof are recombinantly produced, it is also preferably substantially free of culture medium, *i.e.*, culture

medium represents less than about 20%, more preferably less than about 10%, and most preferably less than about 5% of the volume of the protein preparation.

[0122] The language “substantially free of chemical precursors or other chemicals” includes preparations of polypeptide(s) of the present invention (*e.g.*, those in Figures 2-7) or biologically active portion thereof in which the polypeptide is separated from chemical precursors or other chemicals which are involved in the synthesis of the polypeptide. In one embodiment, the language “substantially free of chemical precursors or other chemicals” includes preparations of polypeptide(s) of the present invention (*e.g.*, those in Figures 2-7) or biologically active portion thereof having less than about 30% (by dry weight) of chemical precursors or of proteins not of the present invention, more preferably less than about 20% chemical precursors or of proteins not of the present invention, still more preferably less than about 10% chemical precursors or of proteins not of the present invention, and most preferably less than about 5% chemical precursors or of proteins not of the present invention.

[0123] As used herein, a “biologically active portion” of polypeptide(s) of the present invention (*e.g.*, those in Figures 2-7) include polypeptides which participates in an interaction between PD-1 and a non-PD-1 molecule, PD-L1 and a non-PD-L1 molecule, or PD-L2 and a non-PD-L2 molecule, *e.g.*, a natural ligand of PD-1, *e.g.*, PD-1 ligands, or a natural ligand of PD-1 ligands, *e.g.*, PD-1 or B7-1, respectively. Biologically active portions of a polypeptide(s) of the present invention (*e.g.*, those in Figures 2-7) include peptides comprising amino acid sequences sufficiently identical to or derived from the amino acid sequence of polypeptide(s) of the present invention (*e.g.*, those in Figures 2-7), which include fewer amino acids than the respective, full length polypeptide(s) of the present invention (*e.g.*, those in Figures 2-7), and exhibit at least one activity of the respective polypeptide(s) of the present invention (*e.g.*, those in Figures 2-7). In one embodiment, biologically active portions comprise a domain or motif with the ability to specifically bind PD-1 or a PD-L1 ligand according to the antigen, respectively, to which it was raised or designed to bind. Biologically active portions of polypeptide(s) of the present invention (*e.g.*, those in Figures 2-7) can be used as targets for developing agents which modulate an activity mediated by PD-1, PD-L1, or PD-L2, *e.g.*, immune cell activation or suppression.

[0124] In another embodiment, polypeptide(s) of the present invention (*e.g.*, those in Figures 2-7) has an amino acid sequence shown in Figures 2-7. In other embodiments, the polypeptide is substantially identical to polypeptide(s) shown in Figures 2-7, and retains the functional

activity of the respective polypeptide(s) shown in Figures 2-7, yet differs in amino acid sequence due to mutagenesis, as described in detail in subsection I above. Accordingly, in another embodiment, a polypeptide(s) of the present invention is a polypeptide which comprises an amino acid sequence at least about 71%, 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 99.9% or more identical to a polypeptide(s) shown in Figures 2-7.

[0125] To determine the percent identity of two amino acid sequences or of two nucleic acid sequences, the sequences are aligned for optimal comparison purposes (*e.g.*, gaps can be introduced in one or both of a first and a second amino acid or nucleic acid sequence for optimal alignment and non-identical sequences can be disregarded for comparison purposes). In one embodiment, the length of a reference sequence aligned for comparison purposes is at least 30%, preferably at least 40%, more preferably at least 50%, even more preferably at least 60%, and even more preferably at least 70%, 80%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 99.9% of the length of the reference sequence. The amino acid residues or nucleotides at corresponding amino acid positions or nucleotide positions are then compared. When a position in the first sequence is occupied by the same amino acid residue or nucleotide as the corresponding position in the second sequence, then the molecules are identical at that position (as used herein amino acid or nucleic acid “identity” is equivalent to amino acid or nucleic acid “homology”). The percent identity between the two sequences is a function of the number of identical positions shared by the sequences, taking into account the number of gaps, and the length of each gap, which need to be introduced for optimal alignment of the two sequences.

[0126] The invention also provides chimeric or fusion proteins. As used herein, a “chimeric protein” or “fusion protein” comprises a polypeptide(s) of the present invention (*e.g.*, those in Figures 2-7) operatively linked to a polypeptide not of the present invention. A “polypeptide(s) of the present invention” refers to a polypeptide having an amino acid sequence corresponding to a polypeptide shown in Figures 2-7, whereas a “polypeptide not of the present invention” refers to a polypeptide not having an amino acid sequence corresponding to a polypeptide which is not substantially homologous to a polypeptide shown in Figures 2-7, *e.g.*, a polypeptide which is different from a polypeptide shown in Figures 2-7 and which is derived from the same or a different organism. Within the fusion protein, the term “operatively linked” is intended to indicate that the polypeptide(s) of the present invention and the polypeptide(s) not of the present invention are fused in-frame to each other. The polypeptide(s) not of the present invention can

be fused to the N-terminus or C-terminus of the polypeptide(s) of the present invention and corresponds to a moiety that alters the solubility, binding affinity, stability, or valency of the polypeptide(s) of the present invention.

[0127] For example, in one embodiment, the fusion protein is a GST fusion protein with a polypeptide(s) of the present invention. Such fusion proteins can facilitate the purification of recombinant polypeptides of the invention. In another embodiment, the fusion protein contains a heterologous signal sequence at its N-terminus. In certain host cells (*e.g.*, mammalian host cells), expression and/or secretion of polypeptide(s) of the present invention can be increased through use of a heterologous signal sequence.

[0128] A chimeric or fusion polypeptide(s) of the present invention (*e.g.*, those in Figures 2-7) can be produced by standard recombinant DNA techniques. For example, DNA fragments coding for the different polypeptide sequences are ligated together in-frame in accordance with conventional techniques, for example by employing blunt-ended or stagger-ended termini for ligation, restriction enzyme digestion to provide for appropriate termini, filling-in of cohesive ends as appropriate, alkaline phosphatase treatment to avoid undesirable joining, and enzymatic ligation. In another embodiment, the fusion gene can be synthesized by conventional techniques including automated DNA synthesizers. Alternatively, PCR amplification of gene fragments can be carried out using anchor primers which give rise to complementary overhangs between two consecutive gene fragments which can subsequently be annealed and reamplified to generate a chimeric gene sequence (see, for example, Current Protocols in Molecular Biology, Ausubel et al., eds., John Wiley & Sons: 1992). Moreover, many expression vectors are commercially available that already encode a fusion moiety (*e.g.*, a GST polypeptide).

[0129] The amino acid sequences of polypeptide(s) of the present invention (*e.g.*, those in Figures 2-7) identified herein will enable those of skill in the art to produce polypeptides corresponding to polypeptide(s) of the present invention (*e.g.*, those in Figures 2-7). Such polypeptides can be produced in prokaryotic or eukaryotic host cells by expression of polynucleotides encoding a polypeptide(s) of the present invention (*e.g.*, those in Figures 2-7). Alternatively, such peptides can be synthesized by chemical methods. Methods for expression of heterologous polypeptides in recombinant hosts, chemical synthesis of polypeptides, and *in vitro* translation are well known in the art and are described further in Maniatis et al., Molecular Cloning: A Laboratory Manual (1989), 2nd Ed., Cold Spring Harbor, N. Y.; Berger and Kimmel, Methods in Enzymology, Volume 152, Guide to Molecular Cloning Techniques (1987),

Academic Press, Inc., San Diego, Calif.; Merrifield, J. (1969) *J. Am. Chem. Soc.* 91:501; Chaiken I. M. (1981) *CRC Crit. Rev. Biochem.* 11:255; Kaiser et al. (1989) *Science* 243:187; Merrifield, B. (1986) *Science* 232:342; Kent, S. B. H. (1988) *Annu. Rev. Biochem.* 57:957; and Offord, R. E. (1980) *Semisynthetic Proteins*, Wiley Publishing, which are incorporated herein by reference).

III. Antibodies to PD-1, PD-L1, and/or PD-L2

[0130] Antibodies to PD-1, PD-L1, or PD-L2 described herein may be produced using any methods described herein or known in the art. Monoclonal antibodies (*e.g.*, human antibodies) of the invention can be produced using a variety of known techniques, such as the standard somatic cell hybridization technique described by Kohler and Milstein, *Nature* 256: 495 (1975). Although somatic cell hybridization procedures are preferred, in principle, other techniques for producing monoclonal antibodies also can be employed, *e.g.*, viral or oncogenic transformation of B lymphocytes, phage display technique using libraries of human antibody genes.

[0131] One method for generating hybridomas which produce monoclonal antibodies of the invention is the murine system. Hybridoma production in the mouse is well known in the art, including immunization protocols and techniques for isolating and fusing immunized splenocytes.

[0132] Polyclonal antibodies can be prepared as described above by immunizing a suitable subject with a polypeptide immunogen. The polypeptide antibody titer in the immunized subject can be monitored over time by standard techniques, such as with an enzyme linked immunosorbent assay (ELISA) using immobilized polypeptide. If desired, the antibody directed against the antigen can be isolated from the mammal (*e.g.*, from the blood) and further purified by well known techniques, such as protein A chromatography to obtain the IgG fraction. At an appropriate time after immunization, *e.g.*, when the antibody titers are highest, antibody-producing cells can be obtained from the subject and used to prepare monoclonal antibodies by standard techniques, such as the hybridoma technique originally described by Kohler and Milstein (1975) *Nature* 256:495-497) (see also Brown *et al.* (1981) *J. Immunol.* 127:539-46; Brown *et al.* (1980) *J. Biol. Chem.* 255:4980-83; Yeh *et al.* (1976) *Proc. Natl. Acad. Sci.* 76:2927-31; and Yeh *et al.* (1982) *Int. J. Cancer* 29:269-75), the more recent human B cell hybridoma technique (Kozbor *et al.* (1983) *Immunol. Today* 4:72), the EBV-hybridoma technique (Cole *et al.* (1985) *Monoclonal Antibodies and Cancer Therapy*, Alan R. Liss, Inc.,

pp. 77-96) or trioma techniques. The technology for producing monoclonal antibody hybridomas is well known (see generally Kenneth, R. H. in *Monoclonal Antibodies: A New Dimension In Biological Analyses*, Plenum Publishing Corp., New York, New York (1980); Lerner, E. A. (1981) *Yale J. Biol. Med.* 54:387-402; Gefter, M. L. *et al.* (1977) *Somatic Cell Genet.* 3:231-36). Briefly, an immortal cell line (typically a myeloma) is fused to lymphocytes (typically splenocytes) from a mammal immunized with an immunogen as described above, and the culture supernatants of the resulting hybridoma cells are screened to identify a hybridoma producing a monoclonal antibody that binds to the polypeptide antigen, preferably specifically.

[0133] Any of the many well known protocols used for fusing lymphocytes and immortalized cell lines can be applied for the purpose of generating an anti-PD-1, PD-L1, or PD-L2 monoclonal antibody (see, *e.g.*, Galfre, G. *et al.* (1977) *Nature* 266:55052; Gefter *et al.* (1977) *supra*; Lerner (1981) *supra*; Kenneth (1980) *supra*). Moreover, the ordinary skilled worker will appreciate that there are many variations of such methods which also would be useful. Typically, the immortal cell line (*e.g.*, a myeloma cell line) is derived from the same mammalian species as the lymphocytes. For example, murine hybridomas can be made by fusing lymphocytes from a mouse immunized with an immunogenic preparation of the present invention with an immortalized mouse cell line. Preferred immortal cell lines are mouse myeloma cell lines that are sensitive to culture medium containing hypoxanthine, aminopterin and thymidine ("HAT medium"). Any of a number of myeloma cell lines can be used as a fusion partner according to standard techniques, *e.g.*, the P3-NS1/1-Ag4-1, P3-x63-Ag8.653 or Sp2/O-Ag14 myeloma lines. These myeloma lines are available from the American Type Culture Collection (ATCC), Rockville, Md. Typically, HAT-sensitive mouse myeloma cells are fused to mouse splenocytes using polyethylene glycol ("PEG"). Hybridoma cells resulting from the fusion are then selected using HAT medium, which kills unfused and unproductively fused myeloma cells (unfused splenocytes die after several days because they are not transformed). Hybridoma cells producing a monoclonal antibody of the invention are detected by screening the hybridoma culture supernatants for antibodies that bind a given polypeptide, *e.g.*, using a standard ELISA assay.

[0134] As an alternative to preparing monoclonal antibody-secreting hybridomas, a monoclonal specific for one of the above described polypeptides can be identified and isolated by screening a recombinant combinatorial immunoglobulin library (*e.g.*, an antibody phage display library) with the appropriate polypeptide to thereby isolate immunoglobulin library

members that bind the polypeptide. Kits for generating and screening phage display libraries are commercially available (*e.g.*, the Pharmacia *Recombinant Phage Antibody System*, Catalog No. 27-9400-01; and the Stratagene *SurfZAPTM Phage Display Kit*, Catalog No. 240612).

Additionally, examples of methods and reagents particularly amenable for use in generating and screening an antibody display library can be found in, for example, Ladner *et al.* U.S. Patent No. 5,223,409; Kang *et al.* International Publication No. WO 92/18619; Dower *et al.* International Publication No. WO 91/17271; Winter *et al.* International Publication WO 92/20791; Markland *et al.* International Publication No. WO 92/15679; Breitling *et al.* International Publication WO 93/01288; McCafferty *et al.* International Publication No. WO 92/01047; Garrard *et al.* International Publication No. WO 92/09690; Ladner *et al.* International Publication No. WO 90/02809; Fuchs *et al.* (1991) *Biotechnology (NY)* 9:1369-1372; Hay *et al.* (1992) *Hum. Antibod. Hybridomas* 3:81-85; Huse *et al.* (1989) *Science* 246:1275-1281; Griffiths *et al.* (1993) *EMBO J.* 12:725-734; Hawkins *et al.* (1992) *J. Mol. Biol.* 226:889-896; Clarkson *et al.* (1991) *Nature* 352:624-628; Gram *et al.* (1992) *Proc. Natl. Acad. Sci. USA* 89:3576-3580; Garrard *et al.* (1991) *Biotechnology (NY)* 9:1373-1377; Hoogenboom *et al.* (1991) *Nucleic Acids Res.* 19:4133-4137; Barbas *et al.* (1991) *Proc. Natl. Acad. Sci. USA* 88:7978-7982; and McCafferty *et al.* (1990) *Nature* 348:552-554.

[0135] Additionally, recombinant anti-PD-1, PD-L1, or PD-L2 antibodies, such as chimeric, composite, and humanized monoclonal antibodies, which can be made using standard recombinant DNA techniques, can be generated. Such chimeric, composite, and humanized monoclonal antibodies can be produced by recombinant DNA techniques known in the art, for example using methods described in Robinson *et al.* International Patent Publication PCT/US86/02269; Akira *et al.* European Patent Application 184,187; Taniguchi, M. European Patent Application 171,496; Morrison *et al.* European Patent Application 173,494; Neuberger *et al.* PCT Application WO 86/01533; Cabilly *et al.* U.S. Patent No. 4,816,567; Cabilly *et al.* European Patent Application 125,023; Better *et al.* (1988) *Science* 240:1041-1043; Liu *et al.* (1987) *Proc. Natl. Acad. Sci. USA* 84:3439-3443; Liu *et al.* (1987) *J. Immunol.* 139:3521-3526; Sun *et al.* (1987) *Proc. Natl. Acad. Sci.* 84:214-218; Nishimura *et al.* (1987) *Cancer Res.* 47:999-1005; Wood *et al.* (1985) *Nature* 314:446-449; and Shaw *et al.* (1988) *J. Natl. Cancer Inst.* 80:1553-1559; Morrison, S. L. (1985) *Science* 229:1202-1207; Oi *et al.* (1986) *Biotechniques* 4:214; Winter U.S. Patent 5,225,539; Jones *et al.* (1986) *Nature* 321:552-525; Verhoeyan *et al.* (1988) *Science* 239:1534; and Beidler *et al.* (1988) *J. Immunol.* 141:4053-4060.

[0136] In addition, humanized antibodies can be made according to standard protocols such as those disclosed in US patent 5,565,332. In another embodiment, antibody chains or specific binding pair members can be produced by recombination between vectors comprising nucleic acid molecules encoding a fusion of a polypeptide chain of a specific binding pair member and a component of a replicable generic display package and vectors containing nucleic acid molecules encoding a second polypeptide chain of a single binding pair member using techniques known in the art, *e.g.*, as described in US patents 5,565,332, 5,871,907, or 5,733,743. The use of intracellular antibodies to inhibit protein function in a cell is also known in the art (see *e.g.*, Carlson, J. R. (1988) *Mol. Cell. Biol.* 8:2638-2646; Biocca, S. *et al.* (1990) *EMBO J.* 9:101-108; Werge, T. M. *et al.* (1990) *FEBS Lett.* 274:193-198; Carlson, J. R. (1993) *Proc. Natl. Acad. Sci. USA* 90:7427-7428; Marasco, W. A. *et al.* (1993) *Proc. Natl. Acad. Sci. USA* 90:7889-7893; Biocca, S. *et al.* (1994) *Biotechnology (NY)* 12:396-399; Chen, S-Y. *et al.* (1994) *Hum. Gene Ther.* 5:595-601; Duan, L *et al.* (1994) *Proc. Natl. Acad. Sci. USA* 91:5075-5079; Chen, S-Y. *et al.* (1994) *Proc. Natl. Acad. Sci. USA* 91:5932-5936; Beerli, R. R. *et al.* (1994) *J. Biol. Chem.* 269:23931-23936; Beerli, R. R. *et al.* (1994) *Biochem. Biophys. Res. Commun.* 204:666-672; Mhashilkar, A. M. *et al.* (1995) *EMBO J.* 14:1542-1551; Richardson, J. H. *et al.* (1995) *Proc. Natl. Acad. Sci. USA* 92:3137-3141; PCT Publication No. WO 94/02610 by Marasco *et al.*; and PCT Publication No. WO 95/03832 by Duan *et al.*).

[0137] In another embodiment, human monoclonal antibodies directed against PD-1, PD-L1, or PD-L2 can be generated using transgenic or transchromosomal mice carrying parts of the human immune system rather than the mouse system. In one embodiment, transgenic mice, referred to herein as "HuMAb mice" which contain a human immunoglobulin gene miniloci that encodes unrearranged human heavy (μ and γ) and κ light chain immunoglobulin sequences, together with targeted mutations that inactivate the endogenous μ and κ chain loci (Lonberg, N. *et al.* (1994) *Nature* 368(6474): 856 859). Accordingly, the mice exhibit reduced expression of mouse IgM or κ , and in response to immunization, the introduced human heavy and light chain transgenes undergo class switching and somatic mutation to generate high affinity human IgG κ monoclonal antibodies (Lonberg, N. *et al.* (1994), *supra*; reviewed in Lonberg, N. (1994) *Handbook of Experimental Pharmacology* 113:49 101; Lonberg, N. and Huszar, D. (1995) *Intern. Rev. Immunol.* Vol. 13: 65 93, and Harding, F. and Lonberg, N. (1995) *Ann. N. Y Acad. Sci* 764:536 546). The preparation of HuMAb mice is described in Taylor, L. *et al.* (1992) *Nucleic Acids Research* 20:6287 6295; Chen, J. *et al.* (1993) *International Immunology* 5: 647

656; Tuailon *et al.* (1993) *Proc. Natl. Acad. Sci USA* 90:3720 3724; Choi *et al.* (1993) *Nature Genetics* 4:117 123; Chen, J. *et al.* (1993) *EMBO J.* 12: 821 830; Tuailon *et al.* (1994) *J. Immunol.* 152:2912 2920; Lonberg *et al.*, (1994) *Nature* 368(6474): 856 859; Lonberg, N. (1994) *Handbook of Experimental Pharmacology* 113:49 101; Taylor, L. *et al.* (1994) *International Immunology* 6: 579 591; Lonberg, N. and Huszar, D. (1995) *Intern. Rev. Immunol.* Vol. 13: 65 93; Harding, F. and Lonberg, N. (1995) *Ann. N.Y. Acad. Sci* 764:536 546; Fishwild, D. *et al.* (1996) *Nature Biotechnology* 14: 845 851. See further, U.S. Pat. Nos. 5,545,806; 5,569,825; 5,625,126; 5,633,425; 5,789,650; 5,877,397; 5,661,016; 5,814,318; 5,874,299; and 5,770,429; all to Lonberg and Kay, and GenPharm International; U.S. Pat. No. 5,545,807 to Surani *et al.*; International Publication Nos. WO 98/24884, published on Jun. 11, 1998; WO 94/25585, published Nov. 10, 1994; WO 93/1227, published Jun. 24, 1993; WO 92/22645, published Dec. 23, 1992; WO 92/03918, published Mar. 19, 1992.

[0138] In another embodiment, an antibody for use in the invention is a bispecific antibody. A bispecific antibody has binding sites for two different antigens within a single antibody polypeptide. Antigen binding may be simultaneous or sequential. Triomas and hybrid hybridomas are two examples of cell lines that can secrete bispecific antibodies. Examples of bispecific antibodies produced by a hybrid hybridoma or a trioma are disclosed in U.S. Pat. 4,474,893. Bispecific antibodies have been constructed by chemical means (Staerz *et al.* (1985) *Nature* 314:628, and Perez *et al.* (1985) *Nature* 316:354) and hybridoma technology (Staerz and Bevan (1986) *Proc. Natl. Acad. Sci. USA*, 83:1453, and Staerz and Bevan (1986) *Immunol. Today* 7:241). Bispecific antibodies are also described in U.S. patent 5,959,084. Fragments of bispecific antibodies are described in US patent 5,798,229. Bispecific agents can also be generated by making heterohybridomas by fusing hybridomas or other cells making different antibodies, followed by identification of clones producing and co-assembling both antibodies. They can also be generated by chemical or genetic conjugation of complete immunoglobulin chains or portions thereof such as Fab and Fv sequences. The antibody component can bind to PD-1, PD-L1, and/or a PD-L2 polypeptide. In one embodiment, the bispecific antibody could specifically bind to both a PD-1 ligand and a PD-1 polypeptide.

[0139] Yet another aspect of the invention pertains to anti-PD-1, PD-L1, or PD-L2 polypeptide antibodies that are obtainable by a process comprising, immunizing an animal with an immunogenic PD-1, PD-L1, or PD-L2 polypeptide, respectively, or an immunogenic portion thereof; and then isolating from the animal antibodies that specifically bind to the polypeptide.

[0140] In still another aspect of the invention, partial or known antibody sequences can be used to generate and/or express new antibodies. Antibodies interact with target antigens predominantly through amino acid residues that are located in the six heavy and light chain complementarity determining regions (CDRs). For this reason, the amino acid sequences within CDRs are more diverse between individual antibodies than sequences outside of CDRs. Because CDR sequences are responsible for most antibody-antigen interactions, it is possible to express recombinant antibodies that mimic the properties of specific naturally occurring antibodies by constructing expression vectors that include CDR sequences from the specific naturally occurring antibody grafted onto framework sequences from a different antibody with different properties (see, *e.g.*, Riechmann, L. *et al.*, 1998, *Nature* 332:323-327; Jones, P. *et al.*, 1986, *Nature* 321:522-525; and Queen, C. *et al.*, 1989, *Proc. Natl. Acad. Sci. U.S.A.* 86:10029-10033). Such framework sequences can be obtained from public DNA databases that include germline or non-germline antibody gene sequences. These germline sequences will differ from mature antibody gene sequences because they will not include completely assembled variable genes, which are formed by V(D)J joining during B cell maturation. Germline gene sequences will also differ from the sequences of a high affinity secondary repertoire antibody at individual evenly across the variable region. For example, somatic mutations are relatively infrequent in the amino-terminal portion of framework region. For example, somatic mutations are relatively infrequent in the amino terminal portion of framework region 1 and in the carboxy-terminal portion of framework region 4. Furthermore, many somatic mutations do not significantly alter the binding properties of the antibody. For this reason, it is not necessary to obtain the entire DNA sequence of a particular antibody in order to recreate an intact recombinant antibody having binding properties similar to those of the original antibody (see PCT/US99/05535 filed on Mar. 12, 1999). Partial heavy and light chain sequence spanning the CDR regions is typically sufficient for this purpose. The partial sequence is used to determine which germline and/or non-germline variable and joining gene segments contributed to the recombined antibody variable genes. The germline and/or non-germline sequence is then used to fill in missing portions of the variable regions. Heavy and light chain leader sequences are cleaved during protein maturation and do not contribute to the properties of the final antibody. To add missing sequences, cloned cDNA sequences can be combined with synthetic oligonucleotides by ligation or PCR amplification. Alternatively, the entire variable region can be synthesized as a set of short, overlapping, oligonucleotides and combined by PCR amplification to create an entirely

synthetic variable region clone. This process has certain advantages such as elimination or inclusion of particular restriction sites, or optimization of particular codons. The process can also be used to screen libraries of particular immunoglobulin encoding sequences in one species (*e.g.*, human) to design cognate immunoglobulin encoding sequences from known antibody sequence in another species (*e.g.*, mouse) (see, for example, the Examples section below).

[0141] The nucleotide sequences of heavy and light chain transcripts from a hybridoma are used to design an overlapping set of synthetic oligonucleotides to create synthetic V sequences with identical amino acid coding capacities as the natural sequences. The synthetic heavy and kappa chain sequences can differ from the natural sequences in three ways: strings of repeated nucleotide bases are interrupted to facilitate oligonucleotide synthesis and PCR amplification; optimal translation initiation sites are incorporated according to Kozak's rules (Kozak, 1991, J. Biol. Chem. 266L19867019870); and, HindIII sites are engineered upstream of the translation initiation sites.

[0142] For both the heavy and light chain variable regions, the optimized coding, and corresponding non-coding, strand sequences are broken down into 30-50 nucleotide approximately the midpoint of the corresponding non-coding oligonucleotide. Thus, for each chain, the oligonucleotides can be assembled into overlapping double stranded sets that span segments of 150-400 nucleotides. The pools are then used as templates to produce PCR amplification products of 150-400 nucleotides. Typically, a single variable region oligonucleotide set will be broken down into two pools which are separately amplified to generate two overlapping PCR products. These overlapping products are then combined by PCR amplification to form the complete variable region. It may also be desirable to include an overlapping fragment of the heavy or light chain constant region in the PCR amplification to generate fragments that can easily be cloned into the expression vector constructs.

[0143] The reconstructed heavy and light chain variable regions are then combined with cloned promoter, leader sequence, translation initiation, leader sequence, constant region, 3' untranslated, polyadenylation, and transcription termination, sequences to form expression vector constructs. The heavy and light chain expression constructs can be combined into a single vector, co-transfected, serially transfected, or separately transfected into host cells which are then fused to form a host cell expressing both chains.

[0144] Plasmids for this use are known in the art and include the plasmids provided in the Examples section below. Fully human and chimeric antibodies of the present invention also

include IgG2, IgG3, IgE, IgA, IgM, and IgD antibodies. Similar plasmids can be constructed for expression of other heavy chain isotypes, or for expression of antibodies comprising lambda light chains.

[0145] Thus, in another aspect of the invention, the structural features of known, non-human or human antibodies (*e.g.*, a mouse anti-human anti-PD-1, PD-L1, or PD-L2 antibody, such as antibodies EH12.2H7, 29E.2A3, and 24F.10C12 respectively) are used to create structurally related human anti-human PD-1, PD-L1, or PD-L2 antibodies that retain at least one functional property of the antibodies of the invention, such as binding to PD-1, PD-L1, or PD-L2. Another functional property includes inhibiting binding of EH12.2H7 to PD-1, 29E.2A3 to PD-L1, or 24F.10C12 to PD-L2 in a competition ELISA assay. In some embodiments, the structurally related anti-human PD-1, PD-L1, or PD-L2 antibodies have a lower binding affinity to the antigen as compared to antibody EH12.2H7, 29E.2A3, or 24F.10C12 as measured by the IC50 value as described in Example 2 (*e.g.*, the affinity of the murine reference antibody is no greater than any of 3.0, 2.0, 1.9, 1.8, 1.7, 1.6, 1.5, 1.4, 1.3, 1.2 or 1.1 fold of the structurally related antibody). In some embodiments, the structurally related anti-human PD-1, PD-L1, or PD-L2 antibodies have a higher affinity to the antigen as compared to antibody EH12.2H7, 29E.2A3, or 24F.10C12 as measured by the IC50 value as described in Example 2 (such as the affinity of the structurally related antibody is at least 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, or 2.0 fold of the reference antibody). In addition, one or more CDR or variable regions of the present invention (*e.g.*, Figures 2-7) can be combined recombinantly with known human framework regions and CDRs to create additional, recombinantly-engineered, human anti-PD-1, PD-L1, or PD-L2 antibodies of the invention.

[0146] Since it is well known in the art that antibody heavy and light chain CDR3 domains play a particularly important role in the binding specificity/affinity of an antibody for an antigen, the recombinant antibodies of the invention prepared as set forth above preferably comprise the heavy and light chain CDR3s of variable regions of the present invention (*e.g.*, Figures 2-7). The antibodies further can comprise the CDR2s of variable regions of the present invention (*e.g.*, Figures 2-7). The antibodies further can comprise the CDR1s of variable regions of the present invention (*e.g.*, Figures 2-7). The antibodies can further comprise any combinations of the CDRs.

[0147] The CDR1, 2, and/or 3 regions of the engineered antibodies described above can comprise the exact amino acid sequence(s) as those of variable regions of the present invention

(*e.g.*, Figures 2-7) disclosed herein. However, the ordinarily skilled artisan will appreciate that some deviation from the exact CDR sequences may be possible while still retaining the ability of the antibody to bind PD-1, PD-L1, or PD-L2 effectively (*e.g.*, conservative sequence modifications). Accordingly, in another embodiment, the engineered antibody may be composed of one or more CDRs that are, for example, 50%, 60%, 70%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 99.5% identical to one or more CDRs of the present invention (*e.g.*, Figures 2-7).

[0148] In addition to simply binding PD-1, PD-L1, or PD-L2, engineered antibodies such as those described above may be selected for their retention of other functional properties of antibodies of the invention, such as:

- (1) binding to human PD-1, PD-L1, or PD-L2;
- (2) inhibiting binding of EH12.2H7 to PD-1, 29E.2A3 to PD-L1, or 24F.10C12 to PD-L2;
- (3) binding to human PD-1 and inhibiting the ability of the bound PD-1 to bind to PD-1 ligands (*e.g.*, PD-L1 and/or PD-L2);
- (4) binding to human PD-L1 and inhibiting the ability of the bound PD-L1 to bind to PD-L1 ligands (*e.g.*, PD-1 and/or B7-1);
- (5) binding to human PD-L2 and inhibiting the ability of the bound PD-L2 to bind to PD-L2 ligands (*e.g.*, PD-1).

[0149] Heavy and light chain variable region amino acid sequences for antibody EH12.2H7, 29E.2A3 and 24F.10C12 are shown below.

EH12.2H7 heavy chain variable region

QVQLQQSGAELAKPGASVQMSCKASGYSTSSWIHWVKQRPGQGLEWIGYIYPSTGFT
EYNQKFKDKATLTADKSSSTAYMQLSSLTSEDSAVYYCARWRDSSGYHAMDYWGQG
TSVTVSS (SEQ ID NO:76)

EH12.2H7 light chain variable region

DIVLTQSPASLTVSLGQRATISCRASQSVSTSGYSYMHYQQKPGQPPKLLIKFGSNLES
GIPARFSGSGSGTDFTLNHPVEEEDTATYYCQHSWEIPYTFGGGTKLEIK (SEQ ID
NO:77)

29E.2A3 heavy chain variable region

EVQLQQSGPELVKPGASVKMSCKASGYTFTSYVMHWVKQKPGQGLEWIGYVNPFDG
TKYNEMFKGKATLTSDKSSSTAYMELSSLTSEDSAVYYCARQAWGYPWGQGTLVTVS
A (SEQ ID NO:78)

29E.2A3 light chain variable region

DIVLTQSPASLA VSLGQRATISCRATESVEYYGTSLVQWYQQKPGQPPKLLIYAASSVDS
GVPARFSGSGSGTDFSLTIHPVEEDDIAMYFCQQSRRVPYTFGGGGTKLEIK (SEQ ID
NO:79)

24F.10C12 heavy chain variable region

QVQLQQSAAELARPGASVKMSCKASGYTFTGYTMHWVKQRPGQGLEWIGYINPRSGY
TEYNQKFKDKTTLTADKSSSTAYMQLSSLTSEDSAVYYCARPWFAYWGQGTLVTVSA
(SEQ ID NO:80)

24F.10C12 light chain variable region

DIVMTQSPSSLTVTAGEKVTMSCKSSQSLNLSGNQKNYLTWYQQKPGQPPKLLIYWAS
TRESGVPDRFTGSGSGTDFTLTISSVQAEDLAVYYCQNDYSYPLTFGAGTKLELK (SEQ
ID NO:81)

[0150] Antibodies' activity in inhibiting binding of PD-1, PD-L1, or PD-L2 to its ligand(s) can be determined by testing the ability of the antibody from blocking the binding between PD-1, PD-L1, or PD-L2 and its ligand. A competition ELISA assay in the presence of a labeled ligand and the antibody may be used. For example, to determine if an anti-PD-L1 antibody could block the interaction between PD-1 and PD-L1, a competitive binding experiment is performed. Cells expressing PD-L1 is preincubated with the anti-PD-L1 antibody followed by the addition of biotinylated PD-1-Ig fusion protein. If the anti-PD-L1 antibody blocks the binding of PD-1-Ig in a dose-dependent manner and with high avidity, the anti-PD-L1 antibody is considered as being effective in inhibiting the interaction between PD-1 and PD-L1. Similar tests may be carried out to test antibodies that are effective in inhibiting the interaction of PD-1 and PD-L2.

IV. Recombinant Expression Vectors and Host Cells

[0151] Another aspect of the invention pertains to vectors, preferably expression vectors, containing one, two, or more nucleic acid molecules encoding one or more polypeptides of the present invention (*e.g.*, Figures 2-7) (or a portion thereof). As used herein, the term “vector” refers to a nucleic acid molecule capable of transporting another nucleic acid to which it has been linked. One type of vector is a “plasmid”, which refers to a circular double stranded DNA loop into which additional DNA segments can be ligated. Another type of vector is a viral vector, wherein additional DNA segments can be ligated into the viral genome. Certain vectors are capable of autonomous replication in a host cell into which they are introduced (*e.g.*, bacterial vectors having a bacterial origin of replication and episomal mammalian vectors). Other vectors (*e.g.*, non-episomal mammalian vectors) are integrated into the genome of a host cell upon introduction into the host cell, and thereby are replicated along with the host genome. Moreover, certain vectors are capable of directing the expression of genes to which they are operatively linked. Such vectors are referred to herein as “expression vectors”. In general, expression vectors of utility in recombinant DNA techniques are often in the form of plasmids. In the present specification, “plasmid” and “vector” can be used interchangeably as the plasmid is the most commonly used form of vector. However, the invention is intended to include such other forms of expression vectors, such as viral vectors (*e.g.*, replication defective retroviruses, adenoviruses and adeno-associated viruses), which serve equivalent functions.

[0152] The recombinant expression vectors of the invention comprise a nucleic acid of the invention in a form suitable for expression of the nucleic acid in a host cell, which means that the recombinant expression vectors include one or more regulatory sequences, selected on the basis of the host cells to be used for expression, which is operatively linked to the nucleic acid sequence to be expressed. Within a recombinant expression vector, “operably linked” is intended to mean that the nucleotide sequence of interest is linked to the regulatory sequence(s) in a manner which allows for expression of the nucleotide sequence (*e.g.*, in an *in vitro* transcription/translation system or in a host cell when the vector is introduced into the host cell). The term “regulatory sequence” is intended to include promoters, enhancers and other expression control elements (*e.g.*, polyadenylation signals). Such regulatory sequences are described, for example, in Goeddel (1990) *Methods Enzymol.* 185:3-7. Regulatory sequences include those which direct constitutive expression of a nucleotide sequence in many types of host cells and those which direct expression of the nucleotide sequence only in certain host cells

(*e.g.*, tissue-specific regulatory sequences). It will be appreciated by those skilled in the art that the design of the expression vector can depend on such factors as the choice of the host cell to be transformed, the level of expression of protein desired, and the like. The expression vectors of the invention can be introduced into host cells to thereby produce proteins or peptides, including fusion proteins or peptides, encoded by nucleic acids as described herein.

[0153] The recombinant expression vectors of the invention can be designed for expression of polypeptides of the present invention (*e.g.*, Figures 2-7) in prokaryotic or eukaryotic cells. For example, the polypeptides can be expressed in bacterial cells such as *E. coli*, insect cells (using baculovirus expression vectors), yeast cells, or mammalian cells. Suitable host cells are discussed further in Goeddel (1990) *supra*. Alternatively, the recombinant expression vector can be transcribed and translated *in vitro*, for example using T7 promoter regulatory sequences and T7 polymerase.

[0154] Expression of polypeptides in prokaryotes is most often carried out in *E. coli* with vectors containing constitutive or inducible promoters directing the expression of either fusion or non-fusion proteins. Fusion vectors add a number of amino acids to a polypeptide encoded therein, usually to the amino terminus of the recombinant polypeptide. Such fusion vectors typically serve three purposes: 1) to increase expression of recombinant polypeptide; 2) to increase the solubility of the recombinant polypeptide; and 3) to aid in the purification of the recombinant polypeptide by acting as a ligand in affinity purification. Often, in fusion expression vectors, a proteolytic cleavage site is introduced at the junction of the fusion moiety and the recombinant polypeptide to enable separation of the recombinant polypeptide from the fusion moiety subsequent to purification of the fusion protein. Such enzymes, and their cognate recognition sequences, include Factor Xa, thrombin and enterokinase. Typical fusion expression vectors include pGEX (Pharmacia Biotech Inc; Smith, D. B. and Johnson, K. S. (1988) *Gene* 67:31-40), pMAL (New England Biolabs, Beverly, Mass.) and pRIT5 (Pharmacia, Piscataway, NJ) which fuse glutathione S-transferase (GST), maltose E binding protein, or protein A, respectively, to the target recombinant polypeptide.

[0155] Examples of suitable inducible non-fusion *E. coli* expression vectors include pTrc (Amann et al. (1988) *Gene* 69:301-315) and pET 1 Id (Studier et al. (1990) *Methods Enzymol.* 185:60-89). Target gene expression from the pTrc vector relies on host RNA polymerase transcription from a hybrid *trp-lac* fusion promoter. Target gene expression from the pET 11 d vector relies on transcription from a T7 *gn10-lac* fusion promoter mediated by a coexpressed

viral RNA polymerase (T7 gn1). This viral polymerase is supplied by host strains BL21(DE3) or HMS174(DE3) from a resident prophage harboring a T7 gn1 gene under the transcriptional control of the lacUV 5 promoter.

[0156] One strategy to maximize recombinant polypeptide expression in *E. coli* is to express the polypeptide in host bacteria with impaired capacity to proteolytically cleave the recombinant polypeptide (Gottesman, S. (1990) *Methods Enzymol.* 185:119-128). Another strategy is to alter the nucleic acid sequence of the nucleic acid to be inserted into an expression vector so that the individual codons for each amino acid are those preferentially utilized in *E. coli* (Wada et al. (1992) *Nucleic Acids Res.* 20:2111-2118). Such alteration of nucleic acid sequences of the invention can be carried out by standard DNA synthesis techniques.

[0157] In another embodiment, the expression vector is a yeast expression vector. Examples of vectors for expression in yeast *S. cerevisiae* include pYepSec1 (Baldari et al. (1987) *EMBO J.* 6:229-234), pMFa (Kurjan and Herskowitz (1982) *Cell* 30:933-943), pJRY88 (Schultz et al. (1987) *Gene* 54:113-123), pYES2 (Invitrogen Corporation, San Diego, Calif.), and picZ (Invitrogen Corp, San Diego, Calif.).

[0158] Alternatively, polypeptides of the present invention (*e.g.*, Figures 2-7) can be expressed in insect cells using baculovirus expression vectors. Baculovirus vectors available for expression of polypeptides in cultured insect cells (*e.g.*, Sf 9 cells) include the pAc 'series (Smith et al. (1983) *Mol. Cell Biol.* 3:2156-2165) and the pVL series (Lucklow and Summers (1989) *Virology* 170:31-39).

[0159] In yet another embodiment, a nucleic acid of the present invention (*e.g.*, Figures 2-7) is expressed in mammalian cells using a mammalian expression vector. Examples of mammalian expression vectors include pCDM8 (Seed, B. (1987) *Nature* 329:840) and pMT2PC (Kaufman et al. (1987) *EMBO J.* 6:187-195). When used in mammalian cells, the expression vector's control functions are often provided by viral regulatory elements. For example, commonly used promoters are derived from polyoma, Adenovirus 2, cytomegalovirus and Simian Virus 40. For other suitable expression systems for both prokaryotic and eukaryotic cells see chapters 16 and 17 of Sambrook, J. et al., *Molecular Cloning: A Laboratory Manual*. 2nd ed., Cold Spring Harbor Laboratory, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y., 1989.

[0160] In another embodiment, the recombinant mammalian expression vector is capable of directing expression of the nucleic acid preferentially in a particular cell type (*e.g.*, tissue-specific regulatory elements are used to express the nucleic acid). Tissue-specific regulatory

elements are known in the art. Non-limiting examples of suitable tissue-specific promoters include the albumin promoter (liver-specific; Pinkert et al. (1987) *Genes Dev.* 1:268-277), lymphoid-specific promoters (Calame and Eaton (1988) *Adv. Immunol.* 43:235-275), particular promoters of T cell receptors (Winoto and Baltimore (1989) *EMBO J.* 8:729-733) and immunoglobulins (Banerji et al. (1983) *Cell* 33:729-740; Queen and Baltimore (1983) *Cell* 33:741-748), neuron-specific promoters (*e.g.*, the neurofilament promoter; Byrne and Ruddle (1989) *Proc. Natl. Acad. Sci. USA* 86:5473-5477), pancreas-specific promoters (Edlund et al. (1985) *Science* 230:912-916), and mammary gland-specific promoters (*e.g.*, milk whey promoter; U.S. Pat. No. 4,873,316 and European Application Publication No. 264,166). Developmentally-regulated promoters are also encompassed, for example by the murine hox promoters (Kessel and Gruss (1990) *Science* 249:374-379) and the α -fetoprotein promoter (Campes and Tilghman (1989) *Genes Dev.* 3:537-546).

[0161] Another aspect of the invention pertains to host cells into which a nucleic acid molecule of the present invention (*e.g.*, Figures 2-7) is introduced within a recombinant expression vector or a nucleic acid molecule containing sequences which allow it to homologously recombine into a specific site of the host cell's genome. The terms "host cell" and "recombinant host cell" are used interchangeably herein. It is understood that such terms refer not only to the particular subject cell but to the progeny or potential progeny of such a cell. Because certain modifications may occur in succeeding generations due to either mutation or environmental influences, such progeny may not, in fact, be identical to the parent cell, but are still included within the scope of the term as used herein.

[0162] A host cell can be any prokaryotic or eukaryotic cell. For example, a polypeptide of the present invention (*e.g.*, Figures 2-7) can be expressed in bacterial cells such as *E. coli*, insect cells, yeast or mammalian cells (such as Chinese hamster ovary cells (CHO) or COS cells). Other suitable host cells are known to those skilled in the art.

[0163] Vector DNA can be introduced into prokaryotic or eukaryotic cells via conventional transformation or transfection techniques. As used herein, the terms "transformation" and "transfection" are intended to refer to a variety of art-recognized techniques for introducing foreign nucleic acid (*e.g.*, DNA) into a host cell, including calcium phosphate or calcium chloride co-precipitation, DEAE-dextran-mediated transfection, lipofection, or electroporation. Suitable methods for transforming or transfecting host cells can be found in Sambrook et al. (*Molecular Cloning: A Laboratory Manual*, 2nd, ed., Cold Spring Harbor Laboratory, Cold

Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y., 1989), and other laboratory manuals.

[0164] For stable transfection of mammalian cells, it is known that, depending upon the expression vector and transfection technique used, only a small fraction of cells may integrate the foreign DNA into their genome. In order to identify and select these integrants, a gene that encodes a selectable marker (*e.g.*, resistance to antibiotics) is generally introduced into the host cells along with the gene of interest. Preferred selectable markers include those which confer resistance to drugs, such as G418, hygromycin and methotrexate. Nucleic acid encoding a selectable marker can be introduced into a host cell on the same vector as that encoding a PD-L2 polypeptide or can be introduced on a separate vector. Cells stably transfected with the introduced nucleic acid can be identified by drug selection (*e.g.*, cells that have incorporated the selectable marker gene will survive, while the other cells die).

[0165] A host cell of the invention, such as a prokaryotic or eukaryotic host cell in culture, can be used to produce (*i.e.*, express) a polypeptide of the present invention (*e.g.*, Figures 2-7). Accordingly, the invention further provides methods for producing a polypeptide of the present invention (*e.g.*, Figures 2-7) using the host cells of the present invention. In one embodiment, the method comprises culturing the host cell of the invention (into which a recombinant expression vector encoding a polypeptide of the present invention (*e.g.*, Figures 2-7) has been introduced) in a suitable medium such that a polypeptide of the present invention (*e.g.*, Figures 2-7) is produced. In another embodiment, the method further comprises isolating a polypeptide of the present invention (*e.g.*, Figures 2-7) from the medium or the host cell.

[0166] The host cells of the invention can also be used to produce non-human transgenic animals, as described below.

V. Production of Transgenic and Transchromosomal Nonhuman Animals Which Generate Composite, Human PD-1, PD-L1, or PD-L2 Antibodies

[0167] In yet another aspect, the invention provides transgenic and transchromosomal non-human animals, such as transgenic or transchromosomal mice, which are capable of expressing human monoclonal antibodies that specifically bind to PD-1, PD-L1, or PD-L2. In a particular embodiment, the invention provides a transgenic or transchromosomal mouse having a genome comprising a human heavy chain transgene, such that the mouse produces human anti- PD-1, PD-L1, or PD-L2 antibodies when immunized with PD-1, PD-L1, or PD-L2 antigen and/or cells

expressing PD-1, PD-L1, or PD-L2. The human heavy chain transgene can be integrated into the chromosomal DNA of the mouse, as is the case for transgenic, *e.g.*, HuMAb, mice accordingly to methods well known in the art. Alternatively, the human heavy chain transgene can be maintained extrachromosomally, as is the case for transchromosomal (*e.g.*, KM) mice as described in WO 02/43478. Such transgenic and transchromosomal mice are capable of producing multiple isotypes of human monoclonal antibodies to PD-1, PD-L1, or PD-L2 (*e.g.*, IgG, IgA and/or IgE) by undergoing V-D-J recombination and isotype switching. Isotype switching may occur by, *e.g.*, classical or non-classical isotype switching.

[0168] The design of a transgenic or transchromosomal non-human animal that responds to foreign antigen stimulation with a heterologous antibody repertoire, requires that the heterologous immunoglobulin transgenes contained within the transgenic animal function correctly throughout the pathway of B-cell development. This includes, for example, isotype switching of the heterologous heavy chain transgene. Accordingly, transgenes are constructed so as to produce isotype switching and one or more of the following of antibodies: (1) high level and cell-type specific expression, (2) functional gene rearrangement, (3) activation of and response to allelic exclusion, (4) expression of a sufficient primary repertoire, (5) signal transduction, (6) somatic hypermutation, and (7) domination of the transgene antibody locus during the immune response.

[0169] Not all of the foregoing criteria need be met. For example, in those embodiments wherein the endogenous immunoglobulin loci of the transgenic animal are functionally disrupted, the transgene need not activate allelic exclusion. Further, in those embodiments wherein the transgene comprises a functionally rearranged heavy and/or light chain immunoglobulin gene, the second criteria of functional gene rearrangement is unnecessary, at least for that transgene which is already rearranged. For background on molecular immunology, see, *Fundamental Immunology*, 2nd edition (1989), Paul William E., ed. Raven Press, N.Y.

[0170] In certain embodiments, the transgenic or transchromosomal non-human animals used to generate the human monoclonal antibodies of the invention contain rearranged, unrearranged or a combination of rearranged and unrearranged heterologous immunoglobulin heavy and light chain transgenes in the germline of the transgenic animal. Each of the heavy chain transgenes comprises at least one CH gene. In addition, the heavy chain transgene may contain functional isotype switch sequences, which are capable of supporting isotype switching of a heterologous transgene encoding multiple CH genes in the B-cells of the transgenic animal. Such switch

sequences may be those which occur naturally in the germline immunoglobulin locus from the species that serves as the source of the transgene CH genes, or such switch sequences may be derived from those which occur in the species that is to receive the transgene construct (the transgenic animal). For example, a human transgene construct that is used to produce a transgenic mouse may produce a higher frequency of isotype switching events if it incorporates switch sequences similar to those that occur naturally in the mouse heavy chain locus, as presumably the mouse switch sequences are optimized to function with the mouse switch recombinase enzyme system, whereas the human switch sequences are not. Switch sequences may be isolated and cloned by conventional cloning methods, or may be synthesized de novo from overlapping synthetic oligonucleotides designed on the basis of published sequence information relating to immunoglobulin switch region sequences (Mills *et al.*, Nucl. Acids Res. 15:7305 7316 (1991); Sideras *et al.*, Intl. Immunol. 1:631 642 (1989)). For each of the foregoing transgenic animals, functionally rearranged heterologous heavy and light chain immunoglobulin transgenes are found in a significant fraction of the B-cells of the transgenic animal (at least 10 percent).

[0171] The transgenes used to generate the transgenic animals of the invention include a heavy chain transgene comprising DNA encoding at least one variable gene segment, one diversity gene segment, one joining gene segment and at least one constant region gene segment. The immunoglobulin light chain transgene comprises DNA encoding at least one variable gene segment, one joining gene segment and at least one constant region gene segment. The gene segments encoding the light and heavy chain gene segments are heterologous to the transgenic non-human animal in that they are derived from, or correspond to, DNA encoding immunoglobulin heavy and light chain gene segments from a species not consisting of the transgenic non-human animal. In one aspect of the invention, the transgene is constructed such that the individual gene segments are unrearranged, *i.e.*, not rearranged so as to encode a functional immunoglobulin light or heavy chain. Such unrearranged transgenes support recombination of the V, D, and J gene segments (functional rearrangement) and preferably support incorporation of all or a portion of a D region gene segment in the resultant rearranged immunoglobulin heavy chain within the transgenic non-human animal when exposed to the PD-1, PD-L1, or PD-L2 antigen.

[0172] In an alternate embodiment, the transgenes comprise an unrearranged “mini-locus”. Such transgenes typically comprise a substantial portion of the C, D, and J segments as well as a

subset of the V gene segments. In such transgene constructs, the various regulatory sequences, *e.g.*, promoters, enhancers, class switch regions, splice-donor and splice-acceptor sequences for RNA processing, recombination signals and the like, comprise corresponding sequences derived from the heterologous DNA. Such regulatory sequences may be incorporated into the transgene from the same or a related species of the non-human animal used in the invention. For example, human immunoglobulin gene segments may be combined in a transgene with a rodent immunoglobulin enhancer sequence for use in a transgenic mouse. Alternatively, synthetic regulatory sequences may be incorporated into the transgene, wherein such synthetic regulatory sequences are not homologous to a functional DNA sequence that is known to occur naturally in the genomes of mammals. Synthetic regulatory sequences are designed according to consensus rules, such as, for example, those specifying the permissible sequences of a splice-acceptor site or a promoter/enhancer motif. For example, a minilocus comprises a portion of the genomic immunoglobulin locus having at least one internal (*i.e.*, not at a terminus of the portion) deletion of a non-essential DNA portion (*e.g.*, intervening sequence; intron or portion thereof) as compared to the naturally-occurring germline Ig locus.

[0173] Transgenic and transchromosomal mice employed in the present invention can exhibit immunoglobulin production with a significant repertoire, ideally substantially similar to that of a native mouse. Thus, for example, in embodiments where the endogenous Ig genes have been inactivated, the total immunoglobulin levels can range from about 0.1 to 10 mg/ml of serum, or from about 0.5 to 5 mg/ml, or at least about 1.0 mg/ml. When a transgene capable of effecting a switch to IgG from IgM has been introduced into the transgenic mouse, the adult mouse ratio of serum IgG to IgM can be about 10:1. The IgG to IgM ratio will be much lower in the immature mouse. In general, greater than about 10%, preferably 40 to 80% of the spleen and lymph node B cells express exclusively human IgG protein.

[0174] The repertoire will ideally approximate that shown in a native mouse, usually at least about 10% as high, or 25 to 50% or more. Generally, at least about a thousand different immunoglobulins (ideally IgG), *e.g.*, preferably 10^4 to 10^6 or more, will be produced, depending primarily on the number of different V, J and D regions introduced into the mouse genome. These immunoglobulins will typically recognize about one-half or more of highly antigenic proteins, *e.g.*, staphylococcus protein A. Typically, the immunoglobulins will exhibit an affinity (K_D) for preselected antigens of below 10^{-7} M, such as of below 10^{-8} M, 10^{-9} M or 10^{-10} M or even lower.

[0175] In some embodiments, it may be preferable to generate mice with predetermined repertoires to limit the selection of V genes represented in the antibody response to a predetermined antigen type. A heavy chain transgene having a predetermined repertoire may comprise, for example, human V_H genes which are preferentially used in antibody responses to the predetermined antigen type in humans. Alternatively, some V_H genes may be excluded from a defined repertoire for various reasons (*e.g.*, have a low likelihood of encoding high affinity V regions for the predetermined antigen; have a low propensity to undergo somatic mutation and affinity sharpening; or are immunogenic to certain humans). Thus, prior to rearrangement of a transgene containing various heavy or light chain gene segments, such gene segments may be readily identified, *e.g.* by hybridization or DNA sequencing, as being from a species of organism other than the transgenic animal.

[0176] Transgenic and transchromosomal mice as described above can be immunized with, for example, a purified or enriched preparation of PD-1, PD-L1, or PD-L2 antigen and/or cells expressing PD-1, PD-L1, or PD-L2. Alternatively, the transgenic mice can be immunized with DNA encoding human PD-1, PD-L1, or PD-L2. The mice will then produce B cells which undergo class-switching via intratransgene switch recombination (*cis*-switching) and express immunoglobulins reactive with PD-1, PD-L1, or PD-L2. The immunoglobulins can be human antibodies (also referred to as “human sequence antibodies”), wherein the heavy and light chain polypeptides are encoded by human transgene sequences, which may include sequences derived by somatic mutation and V region recombinatorial joints, as well as germline-encoded sequences; these human antibodies can be referred to as being substantially identical to a polypeptide sequence encoded by a human V_L or V_H gene segment and a human J_L or D_H and J_H segment, even though other non-germline sequences may be present as a result of somatic mutation and differential V-J and V-D-J recombination joints. The variable regions of each antibody chain are typically at least 80 percent encoded by human germline V, J, and, in the case of heavy chains, D, gene segments; frequently at least 85 percent of the variable regions are encoded by human germline sequences present on the transgene; often 90 or 95 percent or more of the variable region sequences are encoded by human germline sequences present on the transgene. However, since non-germline sequences are introduced by somatic mutation and VJ and VDJ joining, the human sequence antibodies will frequently have some variable region sequences (and less frequently constant region sequences) which are not encoded by human V, D, or J gene segments as found in the human transgene(s) in the germline of the mice.

Typically, such non-germline sequences (or individual nucleotide positions) will cluster in or near CDRs, or in regions where somatic mutations are known to cluster.

[0177] Human antibodies which bind to the predetermined antigen can result from isotype switching, such that human antibodies comprising a human sequence γ chain (such as $\gamma 1$, $\gamma 2a$, $\gamma 2B$, or $\gamma 3$) and a human sequence light chain (such as kappa) are produced. Such isotype-switched human antibodies often contain one or more somatic mutation(s), typically in the variable region and often in or within about 10 residues of a CDR) as a result of affinity maturation and selection of B cells by antigen, particularly subsequent to secondary (or subsequent) antigen challenge. These high affinity human antibodies may have binding affinities (K_D) of below 10^{-7} M, such as of below 10^{-8} M, 10^{-9} M, 10^{-10} M, 10^{-10} M or even lower.

[0178] Another aspect of the invention includes B cells derived from transgenic or transchromosomal mice as described herein. The B cells can be used to generate hybridomas expressing human monoclonal antibodies which bind with high affinity (*e.g.*, lower than 10^{-7} M) to human PD-1, PD-L1, or PD-L2.

[0179] The development of high affinity human monoclonal antibodies against PD-1, PD-L1, or PD-L2 can be facilitated by a method for expanding the repertoire of human variable region gene segments in a transgenic mouse having a genome comprising an integrated human immunoglobulin transgene, said method comprising introducing into the genome a V gene transgene comprising V region gene segments which are not present in said integrated human immunoglobulin transgene. Often, the V region transgene is a yeast artificial chromosome comprising a portion of a human V_H or V_L (V_K) gene segment array, as may naturally occur in a human genome or as may be spliced together separately by recombinant methods, which may include out-of-order or omitted V gene segments. Often at least five or more functional V gene segments are contained on the YAC. In this variation, it is possible to make a transgenic mouse produced by the V repertoire expansion method, wherein the mouse expresses an immunoglobulin chain comprising a variable region sequence encoded by a V region gene segment present on the V region transgene and a C region encoded on the human Ig transgene. By means of the V repertoire expansion method, transgenic mice having at least 5 distinct V genes can be generated; as can mice containing at least about 24 V genes or more. Some V gene segments may be non-functional (*e.g.*, pseudogenes and the like); these segments may be retained or may be selectively deleted by recombinant methods available to the skilled artisan, if desired.

[0180] Once the mouse germline has been engineered to contain a functional YAC having an expanded V segment repertoire, substantially not present in the human Ig transgene containing the J and C gene segments, the trait can be propagated and bred into other genetic backgrounds, including backgrounds where the functional YAC having an expanded V segment repertoire is bred into a mouse germline having a different human Ig transgene. Multiple functional YACs having an expanded V segment repertoire may be bred into a germline to work with a human Ig transgene (or multiple human Ig transgenes). Although referred to herein as YAC transgenes, such transgenes when integrated into the genome may substantially lack yeast sequences, such as sequences required for autonomous replication in yeast; such sequences may optionally be removed by genetic engineering (*e.g.*, restriction digestion and pulsed-field gel electrophoresis or other suitable method) after replication in yeast is no longer necessary (*i.e.*, prior to introduction into a mouse ES cell or mouse prozygote). Methods of propagating the trait of human sequence immunoglobulin expression, include breeding a transgenic mouse having the human Ig transgene(s), and optionally also having a functional YAC having an expanded V segment repertoire. Both V_H and V_L gene segments may be present on the YAC. The transgenic mouse may be bred into any background desired by the practitioner, including backgrounds harboring other human transgenes, including human Ig transgenes and/or transgenes encoding other human lymphocyte proteins. The invention also provides a high affinity human sequence immunoglobulin produced by a transgenic mouse having an expanded V region repertoire YAC transgene. Although the foregoing describes a preferred embodiment of the transgenic animal of the invention, other embodiments are contemplated which have been classified in four categories:

- (1) Transgenic animals containing an unrearranged heavy and rearranged light immunoglobulin transgene;
- (2) Transgenic animals containing an unrearranged heavy and unrearranged light immunoglobulin transgene;
- (3) Transgenic animal containing rearranged heavy and an unrearranged light immunoglobulin transgene; and
- (4) Transgenic animals containing rearranged heavy and rearranged light immunoglobulin transgenes.

VI. Antibody Conjugates/Immunotoxins

[0181] In another aspect, the present invention features human PD-1, PD-L1, or PD-L2 antibodies conjugated to a therapeutic moiety, such as a cytotoxin, a drug (*e.g.*, an immunosuppressant) or a radioisotope. When conjugated to a cytotoxin, these antibody conjugates are referred to as “immunotoxins.” A cytotoxin or cytotoxic agent includes any agent that is detrimental to (*e.g.*, kills) cells. Examples include taxol, cytochalasin B, gramicidin D, ethidium bromide, emetine, mitomycin, etoposide, tenoposide, vincristine, vinblastine, colchicin, doxorubicin, daunorubicin, dihydroxy anthracin dione, mitoxantrone, mithramycin, actinomycin D, 1-dehydrotestosterone, glucocorticoids, procaine, tetracaine, lidocaine, propranolol, and puromycin and analogs or homologs thereof. Therapeutic agents include, but are not limited to, antimetabolites (*e.g.*, methotrexate, 6-mercaptopurine, 6-thioguanine, cytarabine, 5-fluorouracil decarbazine), alkylating agents (*e.g.*, mechlorethamine, thioepa chlorambucil, melphalan, carmustine (BSNU) and lomustine (CCNU), cyclophosphamide, busulfan, dibromomannitol, streptozotocin, mitomycin C, and cis-dichlorodiamine platinum (II) (DDP) cisplatin), anthracyclines (*e.g.*, daunorubicin (formerly daunomycin) and doxorubicin), antibiotics (*e.g.*, dactinomycin (formerly actinomycin), bleomycin, mithramycin, and anthramycin (AMC)), and anti-mitotic agents (*e.g.*, vincristine and vinblastine). An antibody of the present invention can be conjugated to a radioisotope, *e.g.*, radioactive iodine, to generate cytotoxic radiopharmaceuticals for treating a related disorder, such as a cancer.

[0182] Conjugated human PD-1, PD-L1, or PD-L2 antibodies can be used diagnostically or prognostically to monitor polypeptide levels in tissue as part of a clinical testing procedure, *e.g.*, to, for example, determine the efficacy of a given treatment regimen. Detection can be facilitated by coupling (*i.e.*, physically linking) the antibody to a detectable substance. Examples of detectable substances include various enzymes, prosthetic groups, fluorescent materials, luminescent materials, bioluminescent materials, and radioactive materials. Examples of suitable enzymes include horseradish peroxidase, alkaline phosphatase, P-galactosidase, or acetylcholinesterase; examples of suitable prosthetic group complexes include streptavidin/biotin and avidin/biotin; examples of suitable fluorescent materials include umbelliferone, fluorescein, fluorescein isothiocyanate, rhodamine, dichlorotriazinylamine fluorescein, dansyl chloride or phycoerythrin; an example of a luminescent material includes luminol; examples of bioluminescent materials include luciferase, luciferin, and aequorin, and examples of suitable radioactive material include ^{125}I , ^{131}I , ^{35}S or ^3H .

[0183] The antibody conjugates of the invention can be used to modify a given biological response. The therapeutic moiety is not to be construed as limited to classical chemical therapeutic agents. For example, the drug moiety may be a protein or polypeptide possessing a desired biological activity. Such proteins may include, for example, an enzymatically active toxin, or active fragment thereof, such as abrin, ricin A, pseudomonas exotoxin, or diphtheria toxin; a protein such as tumor necrosis factor or interferon- γ ; or, biological response modifiers such as, for example, lymphokines, interleukin-1 (“IL-1”), interleukin-2 (“IL-2”), interleukin-6 (“IL-6”), granulocyte macrophage colony stimulating factor (“GM-CSF”), granulocyte colony stimulating factor (“G-CSF”), or other cytokines or growth factors.

[0184] Techniques for conjugating such therapeutic moiety to antibodies are well known, see, *e.g.*, Arnon *et al.*, “Monoclonal Antibodies For Immunotargeting Of Drugs In Cancer Therapy”, in *Monoclonal Antibodies And Cancer Therapy*, Reisfeld *et al.* (eds.), pp. 243 56 (Alan R. Liss, Inc. 1985); Hellstrom *et al.*, “Antibodies For Drug Delivery”, in *Controlled Drug Delivery* (2nd Ed.), Robinson *et al.* (eds.), pp. 623 53 (Marcel Dekker, Inc. 1987); Thorpe, “Antibody Carriers Of Cytotoxic Agents In Cancer Therapy: A Review”, in *Monoclonal Antibodies ‘84: Biological And Clinical Applications*, Pinchera *et al.* (eds.), pp. 475 506 (1985); “Analysis, Results, And Future Prospective Of The Therapeutic Use Of Radiolabeled Antibody In Cancer Therapy”, in *Monoclonal Antibodies For Cancer Detection And Therapy*, Baldwin *et al.* (eds.), pp. 303 16 (Academic Press 1985), and Thorpe *et al.*, “The Preparation And Cytotoxic Properties Of Antibody-Toxin Conjugates”, *Immunol. Rev.*, 62:119 58 (1982).

VII. Pharmaceutical Compositions

[0185] In another aspect, the present invention provides a composition, *e.g.*, a pharmaceutical composition, containing one or a combination of the monoclonal antibodies, or antigen-binding portion(s) thereof (such as antigen-binding fragments), of the present invention, formulated together with a pharmaceutically acceptable carrier. In one embodiment, the compositions include a combination of multiple (*e.g.*, two or more) isolated human antibodies of the invention. Preferably, each of the antibodies of the composition binds to a distinct, pre-selected epitope of PD-1, PD-L1, and/or PD-L2.

[0186] Pharmaceutical compositions of the invention also can be administered in combination therapy, *i.e.*, combined with other agents. For example, the combination therapy can include a composition of the present invention with at least one or more additional therapeutic agents,

such as anti-inflammatory agents, DMARDs (disease-modifying anti-rheumatic drugs), immunosuppressive agents, chemotherapeutics, and psoriasis agents. The pharmaceutical compositions of the invention can also be administered in conjunction with radiation therapy. Co-administration with other antibodies, such as CD4 specific antibodies and IL-2 specific antibodies, are also encompassed by the invention.

[0187] As used herein, “pharmaceutically acceptable carrier” includes any and all solvents, dispersion media, coatings, antibacterial and antifungal agents, isotonic and absorption delaying agents, and the like that are physiologically compatible. Preferably, the carrier is suitable for intravenous, intramuscular, subcutaneous, parenteral, spinal or epidermal administration (*e.g.*, by injection or infusion). Depending on the route of administration, the active compound, *i.e.*, antibody, bispecific and multispecific molecule, may be coated in a material to protect the compound from the action of acids and other natural conditions that may inactivate the compound.

[0188] A “pharmaceutically acceptable salt” refers to a salt that retains the desired biological activity of the parent compound and does not impart any undesired toxicological effects (see *e.g.*, Berge, S. M., *et al.* (1977) J. Pharm. Sci. 66:1 19). Examples of such salts include acid addition salts and base addition salts. Acid addition salts include those derived from nontoxic inorganic acids, such as hydrochloric, nitric, phosphoric, sulfuric, hydrobromic, hydroiodic, phosphorous and the like, as well as from nontoxic organic acids such as aliphatic mono- and dicarboxylic acids, phenyl-substituted alkanoic acids, hydroxy alkanoic acids, aromatic acids, aliphatic and aromatic sulfonic acids and the like. Base addition salts include those derived from alkaline earth metals, such as sodium, potassium, magnesium, calcium and the like, as well as from nontoxic organic amines, such as N,N'-dibenzylethylenediamine, N-methylglucamine, chlorprocaine, choline, diethanolamine, ethylenediamine, procaine and the like.

[0189] A composition of the present invention can be administered by a variety of methods known in the art. As will be appreciated by the skilled artisan, the route and/or mode of administration will vary depending upon the desired results. The active compounds can be prepared with carriers that will protect the compound against rapid release, such as a controlled release formulation, including implants, transdermal patches, and microencapsulated delivery systems. Biodegradable, biocompatible polymers can be used, such as ethylene vinyl acetate, polyanhydrides, polyglycolic acid, collagen, polyorthoesters, and polylactic acid. Many methods for the preparation of such formulations are patented or generally known to those

skilled in the art. See, *e.g.*, Sustained and Controlled Release Drug Delivery Systems, J. R. Robinson, ed., Marcel Dekker, Inc., New York, 1978.

[0190] To administer a compound of the invention by certain routes of administration, it may be necessary to coat the compound with, or co-administer the compound with, a material to prevent its inactivation. For example, the compound may be administered to a subject in an appropriate carrier, for example, liposomes, or a diluent. Pharmaceutically acceptable diluents include saline and aqueous buffer solutions. Liposomes include water-in-oil-in-water CGF emulsions as well as conventional liposomes (Strejan *et al.* (1984) J. Neuroimmunol. 7:27).

[0191] Pharmaceutically acceptable carriers include sterile aqueous solutions or dispersions and sterile powders for the extemporaneous preparation of sterile injectable solutions or dispersion. The use of such media and agents for pharmaceutically active substances is known in the art. Except insofar as any conventional media or agent is incompatible with the active compound, use thereof in the pharmaceutical compositions of the invention is contemplated. Supplementary active compounds can also be incorporated into the compositions.

[0192] Therapeutic compositions typically must be sterile and stable under the conditions of manufacture and storage. The composition can be formulated as a solution, microemulsion, liposome, or other ordered structure suitable to high drug concentration. The carrier can be a solvent or dispersion medium containing, for example, water, ethanol, polyol (for example, glycerol, propylene glycol, and liquid polyethylene glycol, and the like), and suitable mixtures thereof. The proper fluidity can be maintained, for example, by the use of a coating such as lecithin, by the maintenance of the required particle size in the case of dispersion and by the use of surfactants. In many cases, it will be preferable to include isotonic agents, for example, sugars, polyalcohols such as mannitol, sorbitol, or sodium chloride in the composition. Prolonged absorption of the injectable compositions can be brought about by including in the composition an agent that delays absorption, for example, monostearate salts and gelatin.

[0193] Sterile injectable solutions can be prepared by incorporating the active compound in the required amount in an appropriate solvent with one or a combination of ingredients enumerated above, as required, followed by sterilization microfiltration. Generally, dispersions are prepared by incorporating the active compound into a sterile vehicle that contains a basic dispersion medium and the required other ingredients from those enumerated above. In the case of sterile powders for the preparation of sterile injectable solutions, the preferred methods of preparation are vacuum drying and freeze-drying (lyophilization) that yield a powder of the

active ingredient plus any additional desired ingredient from a previously sterile-filtered solution thereof.

[0194] Dosage regimens are adjusted to provide the optimum desired response (*e.g.*, a therapeutic response). For example, a single bolus may be administered, several divided doses may be administered over time or the dose may be proportionally reduced or increased as indicated by the exigencies of the therapeutic situation. For example, the human antibodies of the invention may be administered once or twice weekly by subcutaneous injection or once or twice monthly by subcutaneous injection. It is especially advantageous to formulate parenteral compositions in dosage unit form for ease of administration and uniformity of dosage. Dosage unit form as used herein refers to physically discrete units suited as unitary dosages for the subjects to be treated; each unit contains a predetermined quantity of active compound calculated to produce the desired therapeutic effect in association with the required pharmaceutical carrier. The specification for the dosage unit forms of the invention are dictated by and directly dependent on (a) the unique characteristics of the active compound and the particular therapeutic effect to be achieved, and (b) the limitations inherent in the art of compounding such an active compound for the treatment of sensitivity in individuals.

[0195] In one embodiment, an agent of the invention is an antibody. As defined herein, a therapeutically effective amount of antibody (*i.e.*, an effective dosage) ranges from about 0.001 to 30 mg/kg body weight, or about 0.01 to 25 mg/kg body weight, or about 0.1 to 20 mg/kg body weight, or about 1 to 10 mg/kg, 2 to 9 mg/kg, 3 to 8 mg/kg, 4 to 7 mg/kg, or 5 to 6 mg/kg body weight. The skilled artisan will appreciate that certain factors may influence the dosage required to effectively treat a subject, including but not limited to the severity of the disease or disorder, previous treatments, the general health and/or age of the subject, and other diseases present. Moreover, treatment of a subject with a therapeutically effective amount of an antibody can include a single treatment or, preferably, can include a series of treatments. It will also be appreciated that the effective dosage of antibody used for treatment may increase or decrease over the course of a particular treatment. Changes in dosage may result from the results of diagnostic assays.

[0196] Examples of pharmaceutically-acceptable antioxidants include: (1) water soluble antioxidants, such as ascorbic acid, cysteine hydrochloride, sodium bisulfate, sodium metabisulfite, sodium sulfite and the like; (2) oil-soluble antioxidants, such as ascorbyl palmitate, butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), lecithin, propyl

gallate, alpha-tocopherol, and the like; and (3) metal chelating agents, such as citric acid, ethylenediamine tetraacetic acid (EDTA), sorbitol, tartaric acid, phosphoric acid, and the like.

[0197] For the therapeutic compositions, formulations of the present invention include those suitable for oral, nasal, topical (including buccal and sublingual), rectal, vaginal and/or parenteral administration. The formulations may conveniently be presented in unit dosage form and may be prepared by any methods known in the art of pharmacy. The amount of active ingredient which can be combined with a carrier material to produce a single dosage form will vary depending upon the subject being treated, and the particular mode of administration. The amount of active ingredient which can be combined with a carrier material to produce a single dosage form will generally be that amount of the composition which produces a therapeutic effect. Generally, out of one hundred percent, this amount will range from about 0.001 percent to about ninety percent of active ingredient, alternatively from about 0.005 percent to about 70 percent, or alternatively from about 0.01 percent to about 30 percent.

[0198] Formulations of the present invention which are suitable for vaginal administration also include pessaries, tampons, creams, gels, pastes, foams or spray formulations containing such carriers as are known in the art to be appropriate. Dosage forms for the topical or transdermal administration of compositions of this invention include powders, sprays, ointments, pastes, creams, lotions, gels, solutions, patches and inhalants. The active compound may be mixed under sterile conditions with a pharmaceutically acceptable carrier, and with any preservatives, buffers, or propellants which may be required.

[0199] The phrases “parenteral administration” and “administered parenterally” as used herein means modes of administration other than enteral and topical administration, usually by injection, and includes, without limitation, intravenous, intramuscular, intraarterial, intrathecal, intracapsular, intraorbital, intracardiac, intradermal, intraperitoneal, transtracheal, subcutaneous, subcuticular, intraarticular, subcapsular, subarachnoid, intraspinal, epidural and intrastemal injection and infusion.

[0200] Examples of suitable aqueous and nonaqueous carriers which may be employed in the pharmaceutical compositions of the invention include water, ethanol, polyols (such as glycerol, propylene glycol, polyethylene glycol, and the like), and suitable mixtures thereof, vegetable oils, such as olive oil, and injectable organic esters, such as ethyl oleate. Proper fluidity can be maintained, for example, by the use of coating materials, such as lecithin, by the maintenance of the required particle size in the case of dispersions, and by the use of surfactants.

[0201] These compositions may also contain adjuvants such as preservatives, wetting agents, emulsifying agents and dispersing agents. Prevention of presence of microorganisms may be ensured both by sterilization procedures, supra, and by the inclusion of various antibacterial and antifungal agents, for example, paraben, chlorobutanol, phenol sorbic acid, and the like. It may also be desirable to include isotonic agents, such as sugars, sodium chloride, and the like into the compositions. In addition, prolonged absorption of the injectable pharmaceutical form may be brought about by the inclusion of agents which delay absorption such as aluminum monostearate and gelatin.

[0202] When the compounds of the present invention are administered as pharmaceuticals, to humans and animals, they can be given alone or as a pharmaceutical composition containing, for example, 0.001 to 90% (*e.g.*, 0.005 to 70%, such as 0.01 to 30%) of active ingredient in combination with a pharmaceutically acceptable carrier.

[0203] Regardless of the route of administration selected, the compounds of the present invention, which may be used in a suitable hydrated form, and/or the pharmaceutical compositions of the present invention, are formulated into pharmaceutically acceptable dosage forms by conventional methods known to those of skill in the art.

[0204] Actual dosage levels of the active ingredients in the pharmaceutical compositions of the present invention may be varied so as to obtain an amount of the active ingredient which is effective to achieve the desired therapeutic response for a particular patient, composition, and mode of administration, without being toxic to the patient. The selected dosage level will depend upon a variety of pharmacokinetic factors including the activity of the particular compositions of the present invention employed, or the ester, salt or amide thereof, the route of administration, the time of administration, the rate of excretion of the particular compound being employed, the duration of the treatment, other drugs, compounds and/or materials used in combination with the particular compositions employed, the age, sex, weight, condition, general health and prior medical history of the patient being treated, and like factors well known in the medical arts. A physician or veterinarian having ordinary skill in the art can readily determine and prescribe the effective amount of the pharmaceutical composition required. For example, the physician or veterinarian could start doses of the compounds of the invention employed in the pharmaceutical composition at levels lower than that required in order to achieve the desired therapeutic effect and gradually increase the dosage until the desired effect is achieved. In general, a suitable daily dose of a compositions of the invention will be that amount of the

compound which is the lowest dose effective to produce a therapeutic effect. Such an effective dose will generally depend upon the factors described above. It is preferred that administration be intravenous, intramuscular, intraperitoneal, or subcutaneous, preferably administered proximal to the site of the target. If desired, the effective daily dose of a therapeutic composition may be administered as two, three, four, five, six or more sub-doses administered separately at appropriate intervals throughout the day, optionally, in unit dosage forms. While it is possible for a compound of the present invention to be administered alone, it is preferable to administer the compound as a pharmaceutical formulation (composition).

[0205] Therapeutic compositions can be administered with medical devices known in the art. For example, in one embodiment, a therapeutic composition of the invention can be administered with a needleless hypodermic injection device, such as the devices disclosed in U.S. Pat. Nos. 5,399,163, 5,383,851, 5,312,335, 5,064,413, 4,941,880, 4,790,824, or 4,596,556. Examples of well-known implants and modules useful in the present invention include: U.S. Pat. No. 4,487,603, which discloses an implantable micro-infusion pump for dispensing medication at a controlled rate; U.S. Pat. No. 4,486,194, which discloses a therapeutic device for administering medicants through the skin; U.S. Pat. No. 4,447,233, which discloses a medication infusion pump for delivering medication at a precise infusion rate; U.S. Pat. No. 4,447,224, which discloses a variable flow implantable infusion apparatus for continuous drug delivery; U.S. Pat. No. 4,439,196, which discloses an osmotic drug delivery system having multi-chamber compartments; and U.S. Pat. No. 4,475,196, which discloses an osmotic drug delivery system. Many other such implants, delivery systems, and modules are known to those skilled in the art.

[0206] In certain embodiments, the human monoclonal antibodies of the invention can be formulated to ensure proper distribution *in vivo*. For example, the blood-brain barrier (BBB) excludes many highly hydrophilic compounds. To ensure that the therapeutic compounds of the invention cross the BBB (if desired), they can be formulated, for example, in liposomes. For methods of manufacturing liposomes, see, *e.g.*, U.S. Pat. Nos. 4,522,811; 5,374,548; and 5,399,331. The liposomes may comprise one or more moieties which are selectively transported into specific cells or organs, thus enhance targeted drug delivery (see, *e.g.*, V. V. Ranade (1989) *J. Clin. Pharmacol.* 29:685). Exemplary targeting moieties include folate or biotin (see, *e.g.*, U.S. Pat. No. 5,416,016 to Low *et al.*); mannosides (Umezawa *et al.*, (1988) *Biochem. Biophys. Res. Commun.* 153:1038); antibodies (P. G. Bloeman *et al.* (1995) *FEBS Lett.* 357:140; M. Owais *et al.* (1995) *Antimicrob. Agents Chemother.* 39:180); surfactant protein A receptor (Briscoe *et al.*

(1995) Am. J. Physiol. 1233:134), different species of which may comprise the formulations of the inventions, as well as components of the invented molecules; p120 (Schreier *et al.* (1994) J. Biol. Chem. 269:9090); see also K. Keinanen; M. L. Laukkanen (1994) FEBS Lett. 346:123; J. J. Killion; I. J. Fidler (1994) Immunomethods 4:273. In one embodiment of the invention, the therapeutic compounds of the invention are formulated in liposomes; in another embodiment, the liposomes include a targeting moiety. In yet another embodiment, the therapeutic compounds in the liposomes are delivered by bolus injection to a site proximal to the tumor or infection. The composition must be fluid to the extent that easy syringability exists. It must be stable under the conditions of manufacture and storage and must be preserved against the contaminating action of microorganisms such as bacteria and fungi.

[0207] The composition must be sterile and fluid to the extent that the composition is deliverable by syringe. In addition to water, the carrier can be an isotonic buffered saline solution, ethanol, polyol (for example, glycerol, propylene glycol, and liquid polyethylene glycol, and the like), and suitable mixtures thereof. Proper fluidity can be maintained, for example, by use of coating such as lecithin, by maintenance of required particle size in the case of dispersion and by use of surfactants. In many cases, it is preferable to include isotonic agents, for example, sugars, polyalcohols such as mannitol or sorbitol, and sodium chloride in the composition. Long-term absorption of the injectable compositions can be brought about by including in the composition an agent which delays absorption, for example, aluminum monostearate or gelatin.

[0208] When the active compound is suitably protected, as described above, the compound may be orally administered, for example, with an inert diluent or an assimilable edible carrier.

VIII. Uses and Methods of the Invention

[0209] The antibodies described herein (including derivatives and conjugates of the antibodies) and compositions containing the antibodies can be used in a variety of *in vitro* and *in vivo* diagnostic and therapeutic applications (*e.g.*, by up- or down-modulating the immune response). For example, PD-1 ligand binding to PD-1 or B7-1 transmits an inhibitory signal. Thus, modulation of the interaction between PD-1 and a PD-1 ligand, or between a PD-1 ligand and a B7 polypeptide, results in modulation of the immune response. PD-1 ligands can also costimulate T cells. Thus, in one embodiment, antibodies which block the interaction between a PD-1 ligand and PD-1 or B7 can prevent inhibitory signaling. In one embodiment, antibodies

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that block costimulatory signal of the PD-1 ligand block a costimulatory signal to an immune cell. Furthermore, ligation of PD-L2 can induce cytokine secretion and survival of dendritic cells. Thus, antibodies that block PD-L2 ligation can inhibit dendritic cell survival and reduce cytokine expression by dendritic cells, and through these mechanisms inhibit an immune response. In particular, antibodies

5 described herein are useful for diagnostic, prognostic, prevention, and therapeutic applications related to particular conditions mediated by PD-1, PD-L1, and/or PD-L2, as discussed, for example, in Keir *et al.* (2008) *Annu. Rev. Immunol.* 26:677; Sharpe *et al.*, (2007) *Nat. Immunol.* 8:239; Freeman *et al.* (2007) *J. Exp. Med.* 10:2223.

[0210] In one embodiment, the antibodies and the antigen-binding fragments of the present

10 invention are useful for diagnostic, prognostic, prevention, and therapeutic applications regarding neurodegenerative diseases (geriopsychosis, Alzheimer disease, Down syndrome, Parkinson's disease, Creutzfeldt-jakob disease, diabetic neuropathy, Parkinson syndrome, Huntington's disease, Machado-Joseph disease, amyotrophic lateral sclerosis, diabetic neuropathy, and Creutzfeldt Creutzfeldt-Jakob disease).

15 [0211] In another embodiment, the antibodies and the antigen-binding fragments of the present invention are useful diagnostic, prognostic, prevention, and therapeutic applications (such as treating, and delaying the onset or progression of the diseases) for diseases that accelerate the immune reaction, for example, asthma, autoimmune diseases (glomerular nephritis, arthritis, dilated

20 cardiomyopathy-like disease, ulcerous colitis, Sjogren syndrome, Crohn disease, systemic erythematodes, chronic rheumatoid arthritis, multiple sclerosis, psoriasis, allergic contact dermatitis, polymyositis, pachyderma, periarteritis nodosa, rheumatic fever, vitiligo vulgaris, insulin dependent diabetes mellitus, Behcet disease, Hashimoto disease, Addison disease, dermatomyositis, myasthenia

25 gravis, Reiter syndrome, Graves' disease, anaemia perniciousa, Goodpasture syndrome, sterility disease, chronic active hepatitis, pemphigus, autoimmune thrombopenic purpura, and autoimmune hemolytic anemia, active chronic hepatitis, Addison's disease, anti-phospholipid syndrome, atopic

allergy, autoimmune atrophic gastritis, achlorhydra autoimmune, celiac disease, Cushing's syndrome, dermatomyositis, discoid lupus, erythematosis, Goodpasture's syndrome, Hashimoto's thyroiditis, idiopathic adrenal atrophy, idiopathic thrombocytopenia, insulin-dependent diabetes, Lambert-Eaton

30 syndrome, lupoid hepatitis, some cases of lymphopenia, mixed connective tissue disease, pemphigoid, pemphigus vulgaris, pernicious anemia, phacogenic uveitis, polyarteritis

nodosa, polyglandular autosyndromes, primary biliary cirrhosis, primary sclerosing cholangitis, Raynaud's syndrome, relapsing polychondritis, Schmidt's syndrome, limited scleroderma (or crest syndrome), sympathetic ophthalmia, systemic lupus erythematosus, Takayasu's arteritis, temporal arteritis, thyrotoxicosis, type b insulin resistance, ulcerative colitis and Wegener's granulomatosis).

[0212] In still another embodiment, the antibodies and the antigen-binding fragments of the present invention are useful diagnostic, prognostic, prevention, and therapeutic applications (such as treating, and delaying the onset or progression of the diseases) for therapy and/or prevention for persistent infectious disease (e.g., viral infectious diseases including HPV, HBV, hepatitis C Virus (HCV), retroviruses such as human immunodeficiency virus (HIV-1 and HIV-2), herpes viruses such as Epstein Barr Virus (EBV), cytomegalovirus (CMV), HSV-1 and HSV-2, and influenza virus. Other antigens associated with pathogens that can be utilized as described herein are antigens of various parasites, includes malaria, preferably malaria peptide based on repeats of NANP. In addition, bacterial, fungal and other pathogenic diseases are included, such as *Aspergillus*, *Brugia*, *Candida*, *Chlamydia*, *Coccidia*, *Cryptococcus*, *Dirofilaria*, *Gonococcus*, *Histoplasma*, *Leishmania*, *Mycobacterium*, *Mycoplasma*, *Paramecium*, *Pertussis*, *Plasmodium*, *Pneumococcus*, *Pneumocystis*, *Rickettsia*, *Salmonella*, *Shigella*, *Staphylococcus*, *Streptococcus*, *Toxoplasma* and *Vibrio cholerae*. Exemplary species include *Neisseria gonorrhea*, *Mycobacterium tuberculosis*, *Candida albicans*, *Candida tropicalis*, *Trichomonas vaginalis*, *Haemophilus vaginalis*, Group B *Streptococcus* sp., *Microplasma hominis*, *Hemophilus ducreyi*, *Granuloma inguinale*, *Lymphopathia venereum*, *Treponema pallidum*, *Brucella abortus*, *Brucella melitensis*, *Brucella suis*, *Brucella canis*, *Campylobacter fetus*, *Campylobacter fetus intestinalis*, *Leptospira pomona*, *Listeria monocytogenes*, *Brucella ovis*, *Chlamydia psittaci*, *Trichomonas foetus*, *Toxoplasma gondii*, *Escherichia coli*, *Actinobacillus equuli*, *Salmonella abortus ovis*, *Salmonella abortus equi*, *Pseudomonas aeruginosa*, *Corynebacterium equi*, *Corynebacterium pyogenes*, *Actinobaccilus seminis*, *Mycoplasma bovis genitalium*, *Aspergillus fumigatus*, *Absidia ramosa*, *Trypanosoma equiperdum*, *Babesia caballi*, *Clostridium tetani*, *Clostridium botulinum*; or, a fungus, such as, e.g., *Paracoccidioides brasiliensis*; or other pathogen, e.g., *Plasmodium falciparum*. Also included are National Institute of Allergy and Infectious Diseases (NIAID) priority pathogens. These include Category A agents, such as variola major (smallpox), *Bacillus anthracis* (anthrax), *Yersinia pestis* (plague), *Clostridium botulinum* toxin (botulism), *Francisella tularensis*

(tularemia), filoviruses (Ebola hemorrhagic fever, Marburg hemorrhagic fever), arenaviruses (Lassa (Lassa fever), Junin (Argentine hemorrhagic fever) and related viruses); Category B agents, such as *Coxiella burnetii* (Q fever), *Brucella* species (brucellosis), *Burkholderia mallei* (glanders), alphaviruses (Venezuelan encephalomyelitis, eastern & western equine encephalomyelitis), ricin toxin from *Ricinus communis* (castor beans), epsilon toxin of *Clostridium perfringens*; *Staphylococcus enterotoxin B*, *Salmonella* species, *Shigella dysenteriae*, *Escherichia coli* strain O157:H7, *Vibrio cholerae*, *Cryptosporidium parvum*; Category C agents, such as nipah virus, hantaviruses, tickborne hemorrhagic fever viruses, tickborne encephalitis viruses, yellow fever, and multidrug-resistant tuberculosis; helminths, such as *Schistosoma* and *Taenia*; and protozoa, such as *Leishmania* (e.g., *L. mexicana*) and *Plasmodium*.

[0213] In yet another embodiment, the antibodies or the antigen-binding fragments of the present invention are useful for diagnostic, prognostic, prevention, and therapeutic applications for organ graft rejection, graft-versus-host disease (GVHD), allergic disease, and diseases caused by attenuation of immune reaction, which PD-1, PD-L1, and/or PD-L2 participates, for example, cancer and infectious disease.

[0214] The antibodies or antigen-binding fragments described herein are administered to a subject in accord with known methods, such as by intravenous (e.g., as a bolus or by continuous infusion over a period of time), subcutaneous, intramuscular, intraperitoneal, intracerebrospinal, intra-articular, intrasynovial, intrathecal, or inhalation routes administration.

[0215] A subject is treated if one or more beneficial or desired results, including desirably clinical results, are obtained. For purposes of this invention, beneficial or desired clinical results include, but are not limited to, one or more of the following: decreasing one or more symptoms resulting from the disease, increasing the quality of life of those suffering from the disease, decreasing the dose of other medications required to treat the disease, delaying the progression of the disease, and/or prolonging survival of individuals.

1. Screening Methods

[0216] One aspect of the present invention relates to methods of using antibodies of the present to modulate an immune response by modulating costimulation (such as antibodies that modulate the function of PD-1, PD-L1, or PD-L2). Such methods utilize screening assays, including cell based and non-cell based assays. In one embodiment, the assays provide a method

for identifying antibodies which modulate the interaction of a PD-1 ligand and PD-1. In another embodiment, the assays provide a method for identifying antibodies which modulate the interaction between a PD-1 ligand and a B7 polypeptide.

[0217] In one embodiment, the invention relates to assays for screening candidate or test antibodies which bind to, or modulate the activity of, PD-1, PD-L1, or PD-L2, *e.g.*, modulate the ability of the polypeptide to interact with (*e.g.*, bind to) its cognate binding partner. In one embodiment, a method for identifying an antibody to modulate an immune response entails determining the ability of the antibody to modulate, *e.g.* enhance or inhibit, the interaction between PD-1 and a PD-1 ligand, and further determining the ability of the antibody to modulate the interaction between a PD-1 ligand and a B7 polypeptide. In one embodiment, an antibody that modulates the interaction between the PD-1 ligand and PD-1 (*e.g.*, without modulating the interaction between the PD-1 ligand and the B7 polypeptide is selected). In another embodiment, an antibody that modulates the interaction between a PD-1 ligand and a B7 polypeptide (*e.g.*, without modulating the interaction between the PD-1 ligand and PD-1) is selected.

[0218] In another embodiment, a method for identifying an antibody to decrease an immune response entails determining the ability of a candidate antibody to enhance the interaction between a PD-1 ligand and a B7 polypeptide and selecting an antibody that inhibits the interaction between the PD-1 ligand and the B7 polypeptide. In another embodiment, a method for identifying an antibody to decrease an immune response entails determining the ability of the candidate antibody to enhance the interaction between a PD-1 ligand and PD-1 and selecting an antibody that enhances the interaction between the PD-1 ligand and PD-1

[0219] In one embodiment, an assay is a cell-based assay, comprising contacting a cell expressing PD-1, PD-L1, or PD-L2, with a test antibody and determining the ability of the test antibody to modulate (*e.g.* stimulate or inhibit) the binding of PD-1 or the PD-1 ligand target to its binding partner. Determining the ability of the PD-1, PD-1 ligand or B7 polypeptide to bind to, or interact with, its binding partner can be accomplished, *e.g.*, by measuring direct binding or by measuring a parameter of immune cell activation.

[0220] For example, in a direct binding assay, the PD-1 or PD-1 ligand protein (or their respective target polypeptides) can be coupled with a radioisotope or enzymatic label such that binding of PD-1 ligand to PD-1 or to the B7 polypeptide can be determined by detecting the labeled protein in a complex. For example, PD-1 or PD-1 can be labeled with ¹²⁵I, ³⁵S, ¹⁴C, or

^3H , either directly or indirectly, and the radioisotope detected by direct counting of radioemission or by scintillation counting. Alternatively, PD-1 or PD-1 ligand can be enzymatically labeled with, for example, horseradish peroxidase, alkaline phosphatase, or luciferase, and the enzymatic label detected by determination of conversion of an appropriate substrate to product.

[0221] It is also within the scope of this invention to determine the ability of a compound to modulate the interaction between PD-1 and a PD-1 ligand or between a PD-1 ligand and a B7 polypeptide, without the labeling of any of the interactants. For example, a microphysiometer can be used to detect the interaction of PD-1 and a PD-1 ligand, or between a PD-1 ligand and a B7 polypeptide, with its target polypeptide, without the labeling of either PD-1, PD-1 ligand, B7 polypeptide, or the target polypeptide (McConnell, H. M. *et al.* (1992) *Science* 257:1906-1912). As used herein, a “microphysiometer” (*e.g.*, Cytosensor) is an analytical instrument that measures the rate at which a cell acidifies its environment using a light-addressable potentiometric sensor (LAPS). Changes in this acidification rate can be used as an indicator of the interaction between compound and receptor.

[0222] In another embodiment, determining the ability of the antibody to antagonize the interaction between a given set of polypeptides can be accomplished by determining the activity of one or more members of the set of polypeptides. For example, the activity of PD-1 or a PD-1 ligand can be determined by detecting induction of a cellular second messenger (*e.g.*, tyrosine kinase activity), detecting catalytic/enzymatic activity of an appropriate substrate, detecting the induction of a reporter gene (comprising a target-responsive regulatory element operatively linked to a nucleic acid encoding a detectable marker, *e.g.*, chloramphenicol acetyl transferase), or detecting a cellular response regulated by PD-1 or the PD-1 ligand. Determining the ability of the antibody to bind to or interact with said polypeptide can be accomplished, for example, by measuring the ability of a compound to modulate immune cell costimulation or inhibition in a proliferation assay, or by interfering with the ability of said polypeptide to bind to antibodies that recognize a portion thereof.

[0223] Antibodies that block or inhibit interaction of a PD-1 ligand with a costimulatory receptor as well as antibodies that promote a PD-1 ligand-mediated inhibitory signal can be identified by their ability to inhibit immune cell proliferation, and/or effector function, or to induce anergy when added to an *in vitro* assay. For example, cells can be cultured in the presence of an agent that stimulates signal transduction via an activating receptor. A number of

recognized readouts of cell activation can be employed to measure, cell proliferation or effector function (*e.g.*, antibody production, cytokine production, phagocytosis) in the presence of the activating agent. The ability of a test antibody to block this activation can be readily determined by measuring the ability of the antibody to affect a decrease in proliferation or effector function being measured, using techniques known in the art.

[0224] For example, antibodies of the present invention can be tested for the ability to inhibit or enhance costimulation in a T cell assay, as described in Freeman *et al.* (2000) *J. Exp. Med.* 192:1027 and Latchman *et al.* (2001) *Nat. Immunol.* 2:261. CD4+ T cells can be isolated from human PBMCs and stimulated with activating anti-CD3 antibody. Proliferation of T cells can be measured by ³H thymidine incorporation. An assay can be performed with or without CD28 costimulation in the assay. Similar assays can be performed with Jurkat T cells and PHA-blasts from PBMCs.

[0225] In yet another embodiment, an assay of the present invention is a cell-free assay in which PD-1 or a PD-1 ligand or a biologically active portion thereof, is contacted with a test antibody, and the ability of the test antibody to bind to the polypeptide, or biologically active portion thereof, is determined. Binding of the test antibody to the PD-1 or PD-1 ligand polypeptide can be determined either directly or indirectly as described above. In still another embodiment, the assay includes contacting the polypeptide, or biologically active portion thereof, with its binding partner to form an assay mixture, contacting the assay mixture with a test antibody, and determining the ability of the test antibody to interact with the polypeptide in the assay mixture, wherein determining the ability of the test antibody to interact with the polypeptide comprises determining the ability of the test antibody to preferentially bind to the polypeptide or biologically active portion thereof, as compared to the binding partner.

[0226] For example, a PD-1 ligand and a PD-1 polypeptide can be used to form an assay mixture and the ability of a test antibody to block this interaction can be tested by determining the ability of PD-1 to bind the PD-1 ligand and determining the ability of the PD-1 ligand to bind the PD-1 polypeptide, by one of the methods described above for determining binding. Determining the ability of a PD-1 polypeptide to bind a PD-1 ligand and determining the ability of a PD-1 ligand to bind a B7 polypeptide can also be accomplished using a technology such as real-time Biomolecular Interaction Analysis (BIA) (Sjolander, S. and Urbaniczky, C. (1991) *Anal. Chem.* 63:2338-2345 and Szabo *et al.* (1995) *Curr. Opin. Struct. Biol.* 5:699-705). As used herein, "BIA" is a technology for studying biospecific interactions in real time, without

labeling any of the interactants (*e.g.*, BIAcore). Changes in the optical phenomenon of surface plasmon resonance (SPR) can be used as an indication of real-time reactions between biological polypeptides. PD-1, PD-1 ligand, and B7 polypeptide can be immobilized on a BIAcore chip and antibodies can be tested for binding to PD-1, PD-1 ligand, and B7 polypeptide. An example of using the BIA technology is described by Fitz *et al.* (1997) *Oncogene* 15:613.

[0227] The cell-free assays of the present invention are amenable to use of both soluble and/or membrane-bound forms of proteins (*e.g.*, a PD-1 ligand or PD-1 proteins or biologically active portions thereof, or binding partners to which a PD-1 ligand or PD-1 binds). In the case of cell-free assays in which a membrane-bound form protein is used (*e.g.*, a cell surface PD-1 ligand or PD-1 receptor) it may be desirable to utilize a solubilizing agent such that the membrane-bound form of the protein is maintained in solution. Examples of such solubilizing agents include non-ionic detergents such as n-octylglucoside, n-dodecylglucoside, n-dodecylmaltoside, octanoyl-N-methylglucamide, decanoyl-N-methylglucamide, Triton[®] X-100, Triton[®] X-114, Thesit[®], Isotridecypoly(ethylene glycol ether)_n, 3-[(3-cholamidopropyl)dimethylamminio]-1-propane sulfonate (CHAPS), 3-[(3-cholamidopropyl)dimethylamminio]-2-hydroxy-1-propane sulfonate (CHAPSO), or N-dodecyl=N,N-dimethyl-3-ammonio-1-propane sulfonate.

[0228] In one or more embodiments of the above described assay methods, it may be desirable to immobilize either PD-1, a PD-1 ligand, and a B7 polypeptide, or an appropriate target polypeptide, to facilitate separation of complexed from uncomplexed forms of one or both of the proteins, as well as to accommodate automation of the assay. Binding of a test antibody to PD-1 or a PD-1 ligand can be accomplished in any vessel suitable for containing the reactants. Examples of such vessels include microtiter plates, test tubes, and micro-centrifuge tubes. In one embodiment, a fusion protein can be provided which adds a domain that allows one or both of the proteins to be bound to a matrix. For example, glutathione-S-transferase/ PD-1, PD-1 ligand, or B7 polypeptide fusion proteins, or glutathione-S-transferase/target fusion proteins, can be adsorbed onto glutathione sepharose beads (Sigma Chemical, St. Louis, MO) or glutathione derivatized microtiter plates, which are then combined with the test compound, and the mixture incubated under conditions conducive to complex formation (*e.g.*, at physiological conditions for salt and pH). Following incubation, the beads or microtiter plate wells are washed to remove any unbound components, the matrix immobilized in the case of beads, complex determined either directly or indirectly, for example, as described above. Alternatively, the complexes can

be dissociated from the matrix, and the level of PD-1, PD-1 ligand, or B7 polypeptide binding or activity determined using standard techniques.

[0229] In an alternative embodiment, determining the ability of the test compound to modulate the activity of PD-1 or a PD-1 ligand can be accomplished by determining the ability of the test antibody to modulate the activity of a polypeptide that functions downstream of PD-1 or the PD-1 ligand, *e.g.*, a polypeptide that interacts with the PD-1 ligand, or a polypeptide that functions downstream of PD-1, *e.g.*, by interacting with the cytoplasmic domain of PD-1. For example, levels of second messengers can be determined, the activity of the interactor polypeptide on an appropriate target can be determined, or the binding of the interactor to an appropriate target can be determined as previously described.

[0230] This invention further pertains to novel antibodies identified by the above-described screening assays. Accordingly, it is within the scope of this invention to further use an antibody identified as described herein in an appropriate animal model. For example, an antibody identified as described herein can be used in an animal model to determine the efficacy, toxicity, or side effects of treatment with such an antibody. Alternatively, an antibody identified as described herein can be used in an animal model to determine the mechanism of action of such an antibody. Furthermore, this invention pertains to uses of novel antibodies identified by the above-described screening assays for treatments as described herein.

2. Prophylactic Methods

[0231] In one aspect, the invention relates to a method for preventing in a subject, a disease or condition associated with an unwanted or less than desirable immune response. Subjects at risk for a disease that would benefit from treatment with the claimed antibodies or methods can be identified, for example, by any or a combination of diagnostic or prognostic assays known in the art. Administration of a prophylactic antibody can occur prior to the manifestation of symptoms associated with an unwanted or less than desirable immune response. The appropriate antibody used for treatment can be determined based on clinical indications and can be identified, *e.g.*, using screening assays described herein.

3. Therapeutic Methods

[0232] Another aspect of the invention pertains to therapeutic methods of modulating an immune response, *e.g.*, by modulating the interaction between PD-1 and a PD-1 ligand and/or a PD-1 ligand and a B7 polypeptide. For example, modulation of the interaction between PD-1 and a PD-1 ligand, or between a PD-1 ligand and a B7 polypeptide, results in modulation of the

immune response. Thus, in one embodiment, antibodies which block the interaction between PD-1 and the PD-1 ligand can prevent inhibitory signaling. PD-1 ligands can also enhance costimulatory signals in T cells. Thus, in another embodiment, antibodies that prevent PD-1 ligand from providing a costimulatory signal can inhibit T cell costimulation.

[0233] These modulatory antibodies can be administered *in vitro* (e.g., by contacting the cell with an antibody) or, alternatively, *in vivo* (e.g., by administering the agent to a subject). As such, the present invention relates to methods of treating an individual afflicted with a disease or disorder that would benefit from modulation of an immune response, e.g., by modulation of the interaction between a PD-1 ligand and PD-1, or a B7 polypeptide.

4. Downregulation of Immune Responses

[0234] There are numerous embodiments of the invention for upregulating the inhibitory function or downregulating the costimulatory function of a PD-1 ligand to thereby downregulate immune responses. Downregulation can be in the form of inhibiting or blocking an immune response already in progress, or may involve preventing the induction of an immune response. The functions of activated immune cells can be inhibited by down-regulating immune cell responses, or by inducing specific anergy in immune cells, or both.

[0235] For example, the immune response can be downmodulated using: anti-PD-1 ligand antibodies that blocks costimulation by PD-1 ligand (e.g., while not affecting or increasing the interaction between PD-L1 and PD-1) or which promote the binding of a PD-1 ligand with PD-1, (e.g., while not affecting or while inhibiting costimulation by PD-1 ligand).

[0236] In one embodiment of the invention, tolerance is induced against specific antigens by co-administering an antigen with an antibody which blocks PD-1 ligand costimulation. For example, tolerance can be induced to specific proteins. In one embodiment, immune responses to allergens, or to foreign proteins to which an immune response is undesirable, can be inhibited. For example, patients that receive Factor VIII frequently generate antibodies against this clotting factor. Co-administration of an antibody that blocks a PD-1 ligand-mediated costimulatory signal or an antibody that stimulates a PD-1 mediated inhibitory signal in combination with recombinant factor VIII (or by physically linked to Factor VIII, e.g., by cross-linking) can result in downmodulation.

[0237] In one embodiment, two separate agents that downmodulate immune responses can be combined as a single composition or administered separately (simultaneously or sequentially) to

more effectively downregulate immune cell mediated immune responses in a subject. Furthermore, a therapeutically active amount of one or more of the subject antibodies, can be used in conjunction with other downmodulating reagents to influence immune responses. Examples of other immunomodulating reagents include, without limitation, antibodies that block a costimulatory signal, (*e.g.*, against CD28 or ICOS), antibodies that act as agonists of CTLA4, and/or antibodies against other immune cell markers (*e.g.*, against CD40, against CD40 ligand, or against cytokines), fusion proteins (*e.g.*, CTLA4-Fc), and immunosuppressive drugs, (*e.g.*, rapamycin, cyclosporine A or FK506).

[0238] Downregulating or preventing a PD-1 ligand costimulation, or promoting an interaction between a PD-1 ligand and PD-1 is useful to downmodulate the immune response, *e.g.*, in situations of tissue, skin and organ transplantation, in graft-versus-host disease (GVHD), or in inflammatory diseases such as systemic lupus erythematosus, and multiple sclerosis. For example, blockage of immune cell function results in reduced tissue destruction in tissue transplantation. Typically, in tissue transplants, rejection of the transplant is initiated through its recognition as foreign by immune cells, followed by an immune reaction that destroys the transplant. The administration of an antibody which inhibits PD-1 ligand costimulation alone or in conjunction with another downmodulatory agent, prior to or at the time of transplantation can promote the generation of an inhibitory signal. Moreover, inhibition of PD-1 ligand costimulatory signals, or promotion of a PD-1 ligand or PD-1 inhibitory signals, may also be sufficient to anergize the immune cells, thereby inducing tolerance in a subject. Induction of long-term tolerance by blocking a PD-1 ligand mediated costimulatory signal may avoid the necessity of repeated administration of these blocking reagents.

[0239] To achieve sufficient immunosuppression or tolerance in a subject, it may also be desirable to block the costimulatory function of other polypeptides. For example, it may be desirable to block the function of B7-1, B7-2, or B7-1 and B7-2 by administering a soluble form of a combination of peptides having an activity of each of these antigens, blocking antibodies against these antigens or blocking small molecules (separately or together in a single composition) prior to or at the time of transplantation. Alternatively, it may be desirable to promote inhibitory activity of a PD-1 ligand or PD-1 and inhibit a costimulatory activity of B7-1 and/or B7-2. Other downmodulatory agents that can be used in connection with the downmodulatory methods of the invention include, for example, agents that transmit an inhibitory signal via CTLA4, soluble forms of CTLA4, antibodies that activate an inhibitory

signal via CTLA4, blocking antibodies against other immune cell markers or soluble forms of other receptor ligand pairs (*e.g.*, agents that disrupt the interaction between CD40 and CD40 ligand (*e.g.*, anti CD40 ligand antibodies)), antibodies against cytokines, or immunosuppressive drugs.

[0240] Downmodulation of immune responses are also useful in treating autoimmune disease. Many autoimmune disorders are the result of inappropriate activation of immune cells that are reactive against self tissue and which promote the production of cytokines and autoantibodies involved in the pathology of the diseases. Preventing the activation of autoreactive immune cells may reduce or eliminate disease symptoms. Administration of reagents which block costimulation of immune cells by disrupting interactions between PD-1 ligand and B7 polypeptides, or by promoting the interaction between PD-1 ligand and PD-1, without modulating or while downmodulating the interaction between PD-1 ligand and a B7 polypeptide, are useful for inhibiting immune cell activation and preventing production of autoantibodies or cytokines which may be involved in the disease process. Additionally, agents that promote an inhibitory function of a PD-1 ligand or PD-1 may induce antigen-specific tolerance of autoreactive immune cells, which could lead to long-term relief from the disease. The efficacy of reagents in preventing or alleviating autoimmune disorders can be determined using a number of well-characterized animal models of human autoimmune diseases. Examples include murine experimental autoimmune encephalitis, systemic lupus erythematosus in MRL/*lpr/lpr* mice or NZB hybrid mice, murine autoimmune collagen arthritis, diabetes mellitus in NOD mice and BB rats, and murine experimental myasthenia gravis (see, *e.g.*, Paul ed., *Fundamental Immunology*, Raven Press, New York, Third Edition 1993, chapter 30).

[0241] Inhibition of immune cell activation is useful therapeutically in the treatment of allergy and allergic reactions, *e.g.*, by inhibiting IgE production. An antibody that promotes a PD-1 ligand or PD-1 inhibitory function can be administered to an allergic subject to inhibit immune cell mediated allergic responses in the subject. Inhibition of PD-1 ligand costimulation of immune cells or stimulation of a PD-1 ligand or PD-1 inhibitory pathway can be accompanied by exposure to allergen in conjunction with appropriate MHC polypeptides. Allergic reactions can be systemic or local in nature, depending on the route of entry of the allergen and the pattern of deposition of IgE on mast cells or basophils. Thus, inhibition of immune cell mediated allergic responses locally or systemically by administration of an inhibitory form of an agent that

inhibits the interaction of a PD-1 ligand with a costimulatory receptor, or an antibody that promotes an inhibitory function of a PD-1 ligand or PD-1.

[0242] Inhibition of immune cell activation through blockage of PD-1 ligand costimulation, or through promotion of the interaction between a PD-1 ligand and PD-1, may also be important therapeutically in viral infections of immune cells. For example, in the acquired immune deficiency syndrome (AIDS), viral replication is stimulated by immune cell activation. Modulation of these interactions may result in inhibition of viral replication and thereby ameliorate the course of AIDS. Modulation of these interactions may also be useful in promoting the maintenance of pregnancy. PD-1 ligand is normally highly expressed in placental trophoblasts, the layer of cells that forms the interface between mother and fetus and may play a role in preventing maternal rejection of the fetus. Females at risk for spontaneous abortion (*e.g.*, those who have previously had a spontaneous abortion or those who have had difficulty conceiving) because of immunologic rejection of the embryo or fetus can be treated with agents that modulate these interactions.

[0243] Downregulation of an immune response by modulation of PD-1 ligand costimulation or by modulation of PD-1 ligand / PD-1 binding may also be useful in treating an autoimmune attack of autologous tissues. For example, PD-1 ligand is normally highly expressed in the heart and may protect the heart from autoimmune attack. This is evidenced by the fact that the Balb/c PD-1 knockout mouse exhibits massive autoimmune attack on the heart with thrombosis. Thus, conditions that are caused or exacerbated by autoimmune attack (*e.g.*, in this example, heart disease, myocardial infarction or atherosclerosis) may be ameliorated or improved by modulation of these interactions. It is therefore within the scope of the invention to modulate conditions exacerbated by autoimmune attack, such as autoimmune disorders (as well as conditions such as heart disease, myocardial infarction, and atherosclerosis).

5. Upregulation of Immune Responses

[0244] Also useful therapeutically is the blockage of the interaction of a PD-1 ligand with PD-1 or B7-1 as a means of upregulating an immune response. Upregulation of immune responses can be in the form of enhancing an existing immune response or eliciting an initial immune response. For instance, enhancing an immune response using the subject compositions and methods is useful in cases of infections with microbes (*e.g.*, bacteria, viruses, or parasites). In one embodiment, an antibody that blocks the interaction of a PD-1 ligand with PD-1 is used to

enhance the immune response. Such an antibody (*e.g.*, a non-activating antibody that blocks PD-L1 binding to PD-1) is therapeutically useful in situations where upregulation of antibody and cell-mediated responses would be beneficial. Exemplary disorders include viral skin diseases, such as Herpes or shingles, in which case such an agent can be delivered topically to the skin. In addition, systemic viral diseases such as influenza, the common cold, and encephalitis might be alleviated by systemic administration of such agents.

[0245] Alternatively, immune responses can be enhanced in an infected patient through an *ex vivo* approach, for instance, by removing immune cells from the patient, contacting immune cells *in vitro* with an antibody that blocks the interaction of a PD-1 ligand with PD-1 and reintroducing the *in vitro* stimulated immune cells into the patient.

[0246] In certain instances, it may be desirable to further administer other agents that upregulate immune responses, for example, forms of other B7 family members that transduce signals via costimulatory receptors, in order to further augment the immune response.

[0247] An antibody that blocks the interaction of a PD-1 ligand with PD-1 or B7-1 can be used prophylactically in vaccines against various polypeptides (*e.g.*, polypeptides derived from pathogens). Immunity against a pathogen (*e.g.*, a virus) can be induced by vaccinating with a viral protein along with an antibody that blocks the interaction of a PD-1 ligand with PD-1 or B7-1 in an appropriate adjuvant.

[0248] In another embodiment, upregulation or enhancement of an immune response function, as described herein, is useful in the induction of tumor immunity

[0249] In another embodiment, the immune response can be stimulated by the methods described herein, such that preexisting tolerance is overcome. For example, immune responses against antigens to which a subject cannot mount a significant immune response, *e.g.*, to an autologous antigen, such as a tumor specific antigens can be induced by administering an antibody that blocks the interaction of a PD-1 ligand with PD-1. In one embodiment, an autologous antigen, such as a tumor-specific antigen can be coadministered. In another embodiment, an immune response can be stimulated against an antigen (*e.g.*, an autologous antigen) to treat a neurological disorder. In another embodiment, the subject agents can be used as adjuvants to boost responses to foreign antigens in the process of active immunization.

[0250] In one embodiment, immune cells are obtained from a subject and cultured *ex vivo* in the presence of an antibody as described herein, to expand the population of immune cells and/or to enhance immune cell activation. In a further embodiment the immune cells are then

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administered to a subject. Immune cells can be stimulated *in vitro* by, for example, providing to the immune cells a primary activation signal and a costimulatory signal, as is known in the art. Various agents can also be used to costimulate proliferation of immune cells. In one embodiment immune cells are cultured *ex vivo* according to the method described in PCT Application No. WO 94/29436. The
 5 costimulatory polypeptide can be soluble, attached to a cell membrane, or attached to a solid surface, such as a bead.

[0251] Other embodiments of the present invention are described in the following Examples. The present invention is further illustrated by the following examples which should not be construed as further limiting.

10 EXAMPLES

[0252] The examples below describe the generation of monoclonal antibodies suitable for therapeutic purposes targeting human PD-1, PD-L1 and PD-L2. Composite, human anti-human PD-1, PD-L1 and PD-L2 antibodies were generated from mouse anti-human EH12.2H7, 29E.2A3 and 24F.10C12 antibodies, respectively. Segments of human V region sequence were sourced from
 15 unrelated human antibody (germline and non-germline) sequence databases. Each selected sequence segment (as well as the junctions between segments) was tested for the potential to bind to MHC class II using binding prediction algorithms. All final composite, human antibody sequence variants were designed to avoid T cell epitopes. Composite, human antibody V region genes were generated using synthetic oligonucleotides encoding combinations of the human sequence segments. These were
 20 then cloned into vectors containing human constant regions, and antibodies were produced and tested for binding to target antigens by competition ELISA.

Example 1: Design of Composite, Human Antibody Variable Region Sequences

[0253] Structural models of the mouse EH12.2H7, 29E.2A3 and 24F.10C12 V regions were produced using Swiss Pdb and analyzed in order to identify important “constraining” amino acids in
 25 the mouse V regions that might be essential for the binding properties of the antibodies. Only residues contained within the CDRs were considered to be important, including CDR residues defined under both Kabat and Chothia definitions.

[0254] From the above analysis, it was considered that composite, human forms of EH12.2H7, 29E.2A3 and 24F.10C12 could be created with wide latitude of sequences outside of CDRs but with a narrow menu of possible alternative residues within the CDR sequences. Preliminary analysis indicated that corresponding sequence segments from several human antibodies could be combined to create CDRs similar or identical to those in the mouse sequences. For regions outside of and flanking the CDRs, a wide selection of human sequence segments were identified as possible components of the novel composite, human antibody variable regions.

[0255] Based upon the above analysis, a large preliminary set of sequence segments that could be used to create EH12.2H7, 29E.2A3 and 24F.10C12 composite, human antibody variants were selected and analyzed via MHC class II binding prediction algorithms and BLAST searched through a proprietary database of known antibody sequence related T cell epitopes. Sequence segments where potential MHC class II binding peptides were identified, or scored significant hits against the database of known T cell epitopes, were discarded. This resulted in a reduced set of segments, and combinations of these were again analyzed, as above, to ensure that junctions between segments did not contain potential T cell epitopes. Selected segments were then combined to produce heavy and light chain variable region sequences for synthesis. For all three antibodies, five heavy chains and four light chains were constructed with sequences detailed as follows;

Antigen	Composite VH Sequences	Composite VK Sequences
PD-1	Figure 2 (A-E)	Figure 3 (A-D)
PD-L1	Figure 4 (A-E)	Figure 5 (A-D)
PD-L2	Figure 6 (A-E)	Figure 7 (A-D)

[0256] Sequence segments used to produce these composite, human antibody sequences are detailed in Tables 1, 2, and 3 for antibodies against PD-1, PD-L1 and PD-L2 respectively.

Table 1. Derivation of Human Sequence Segments that Comprise the Anti-PD-1 Composite, Human Antibodies

Genbank Accession No.	VH3 Sequence	(a)
BAA75018	QVQLVQSGHEVKQPGASVK (SEQ ID NO:82)	
AAG00910	MSCKASGYSFTS (SEQ ID NO:83)	
AAV18543	SGYSFTSSWI (SEQ ID NO:84)	
AAV57105	WIHWV (SEQ ID NO:85)	
AAG00910	KQ	
AAD16517	QAPGQGLEWIG (SEQ ID NO:86)	
AAD53797	GLEWIGYIYPS (SEQ ID NO:87)	
CAA08742	STGF (SEQ ID NO:88)	
CAC87219	TEYN (SEQ ID NO:89)	
AAT96419	QKF	
AAA17939	KDR	
AAR02530	DRAT (SEQ ID NO:90)	
AAA17939	TLT	
AAM87977	TADKSTSTAYMELSSLRSEDVAVYYCAR (SEQ ID NO:91)	
CAA78534	STAYMELSSLRSEDVAVYYCARWRD (SEQ ID NO:92)	
AAV40096	DSSGY (SEQ ID NO:93)	
AAR38557	YHA	
AAW29142	AMD	
IGHJ4	DYWGQGTLVTVSS (SEQ ID NO:94)	

Genbank Accession No.	VH4 Sequence	(b)
BAA75018	QVQLVQSGHEVKQPGASVK (SEQ ID NO:82)	
AAG00910	MSCKASGYSFTS (SEQ ID NO:83)	
AAV18543	SGYSFTSSWI (SEQ ID NO:84)	
AAA02616	HWVRQAPGQGLEWIG (SEQ ID NO:95)	
AAD53797	GLEWIGYIYPS (SEQ ID NO:87)	
CAA08742	STGF (SEQ ID NO:88)	
CAC87219	TEYN (SEQ ID NO:89)	
AAT96419	QKF	
AAA17939	KDR	
AAR02530	DRAT (SEQ ID NO:90)	
AAA17939	TLT	
AAM87977	TADKSTSTAYMELSSLRSEDVAVYYCAR (SEQ ID NO:91)	
CAA78534	STAYMELSSLRSEDVAVYYCARWRD (SEQ ID NO:92)	
AAV40096	DSSGY (SEQ ID NO:93)	
AAR38557	YHA	
AAW29142	AMD	
IGHJ4	DYWGQGTLVTVSS (SEQ ID NO:94)	

Table 1 cont.:

Genbank Accession No.	Vκ3 Sequence
AAY16615	EIVLTQSPATLSLSPGQR (SEQ ID NO:96)
AAD09377	RLTISCRASQ (SEQ ID NO:97)
AAA99362	TISCRASQSVST (SEQ ID NO:98)
AAL04518	SVSTSGYSYMHW (SEQ ID NO:99)
AAA58912	WYQQKPDQSPKLLIK (SEQ ID NO:100)
AAD16648	FGS
AAD19478	SNLESG (SEQ ID NO:101)
AAL10884	GIPARFSGSGSGTDFTLTISSELPEDFA (SEQ ID NO:102)
AAD16559	PEDFATYYCQHS (SEQ ID NO:103)
AAA99326	SW
AAC16811	EIP
human J2	YTFGQGTKLEIK (SEQ ID NO:104)

(c)

Genbank Accession No.	Vκ4 Sequence
AAB53267	DIVLTQSP (SEQ ID NO:105)
AAY16615	IVLTQSPATLSLSPGQR (SEQ ID NO:106)
AAD09377	RLTISCRASQ (SEQ ID NO:97)
AAA99362	TISCRASQSVST (SEQ ID NO:98)
AAL04518	SVSTSGYSYMHW (SEQ ID NO:99)
AAA58912	WYQQKPDQSPKLLIK (SEQ ID NO:100)
AAD16648	FGS
AAD19478	SNLESG (SEQ ID NO:101)
AAL10884	GIPARFSGSGSGTDFTLTISSELPEDFA (SEQ ID NO:102)
AAD16559	PEDFATYYCQHS (SEQ ID NO:103)
AAA99326	SW
AAC16811	EIP
human J2	YTFGQGTKLEIK (SEQ ID NO:104)

(d)

Table 2. Derivation of Human Sequence Segments that Comprise the Anti-PD-L1 Composite, Human Antibodies

Genbank Accession No.	VH2 Sequence	(a)
ABI50688	EVQLVQSGAEVKKPGASVK (SEQ ID NO:107)	
AAG00910	MSCKASGY (SEQ ID NO:108)	
ABI50688	SCKASGYTFTSY (SEQ ID NO:109)	
AAC50839	SYVMHWV (SEQ ID NO:110)	
CAC43594	WVKQ (SEQ ID NO:111)	
AAA18267	QAPGQRLEWIG (SEQ ID NO:112)	
ABF20472	GY	
AAD30737	VNPF (SEQ ID NO:113)	
CAL06274	NDGT (SEQ ID NO:114)	
CAC43212	KYN	
CAC87219	YNE	
CAD31770	EM	
AAR32413	FKGR (SEQ ID NO:115)	
AAG30515	GRAT (SEQ ID NO:116)	
ABA62048	TLT	
ABI50549	TSD	
AAR32572	DKSTSTAYMELSSLRSEDVAVYYCA (SEQ ID NO:117)	
AAC18225	AVYYCARQA (SEQ ID NO:118)	
AAV39747	AWGY (SEQ ID NO:119)	
IGHJ5*02	PWGQGTILVTVSS (SEQ ID NO:120)	
Genbank Accession No.	VH4 Sequence	(b)
ABI50688	EVQLVQSGAEVKKPGASVK (SEQ ID NO:107)	
AAG00910	MSCKASGY (SEQ ID NO:108)	
ABI50688	SCKASGYTFTSY (SEQ ID NO:109)	
AAC50839	SYVMHWV (SEQ ID NO:110)	
AAA18267	WVRQAPGQRLEWIG (SEQ ID NO:121)	
ABF20472	GY	
AAD30737	VNPF (SEQ ID NO:113)	
CAL06274	NDGT (SEQ ID NO:114)	
CAC43212	KYN	
CAC87219	YNE	
CAD31770	EM	
AAR32413	FKGR (SEQ ID NO:115)	
AAG30515	GRAT (SEQ ID NO:116)	
ABA62048	TLT	
ABI50549	TSD	
AAR32572	DKSTSTAYMELSSLRSEDVAVYYCA (SEQ ID NO:117)	
AAC18225	AVYYCARQA (SEQ ID NO:118)	
AAV39747	AWGY (SEQ ID NO:119)	
IGHJ5*02	PWGQGTILVTVSS (SEQ ID NO:120)	

Table 2 cont.:

Genbank Accession No.	Vk1 Sequence
CAA31193	DIVLTQSPASLALS (SEQ ID NO:122)
ABA26115	LSPGERAT (SEQ ID NO:123)
AAQ21828	ESV
CAA51101	VE
AAA58691	YYGTSL (SEQ ID NO:124)
AAV33369	VQWYQQKPGQ (SEQ ID NO:125)
ABI74051	WYQQKPGQPPKLLIY (SEQ ID NO:126)
CAC39383	PKLLIYAASS (SEQ ID NO:127)
CAA38592	SVDS (SEQ ID NO:128)
AAK26833	DSGVPSRFSGSGSGT (SEQ ID NO:129)
AAM46660	RFSGSGSGTDFTLTINSLE (SEQ ID NO:130)
AAL04518	EEEDAA (SEQ ID NO:131)
AAK68016	AMYFCQQ (SEQ ID NO:132)
CAK50767	SR
AAP23227	RVPYTFG (SEQ ID NO:133)
Human J2	YTFGQGKLEIK (SEQ ID NO:104)

(c)

Genbank Accession No.	Vk2 Sequence
CAA31193	DIVLTQSPASLALS (SEQ ID NO:122)
CAE54363	IVLTQSPATLSLSPGE (SEQ ID NO:134)
ABA26115	LSPGERAT (SEQ ID NO:123)
AAQ21828	ESV
CAA51101	VE
AAA58691	YYGTSL (SEQ ID NO:124)
AAV33369	VQWYQQKPGQ (SEQ ID NO:125)
ABI74051	WYQQKPGQPPKLLIY (SEQ ID NO:126)
CAC39383	PKLLIYAASS (SEQ ID NO:127)
CAA38592	SVDS (SEQ ID NO:128)
AAK26833	DSGVPSRFSGSGSGT (SEQ ID NO:129)
AAM46660	RFSGSGSGTDFTLTINSLE (SEQ ID NO:130)
AAA58912	TINSLEAEDAA (SEQ ID NO:135)
AAK68016	AMYFCQQ (SEQ ID NO:132)
CAK50767	SR
AAP23227	RVPYTFG (SEQ ID NO:133)
Human J2	YTFGQGKLEIK (SEQ ID NO:104)

(d)

Table 2 cont.:

Genbank Accession No.	Vκ4 Sequence
CAA31193	DIVLTQSPASLALS (SEQ ID NO:122)
CAE54363	IVLTQSPATLSLSPGE (SEQ ID NO:134)
ABA26115	LSPGERAT (SEQ ID NO:123)
AAQ21828	ESV
CAA51101	VE
AAA58691	YYGTSL (SEQ ID NO:124)
AAV33369	VQWYQQKPGQ (SEQ ID NO:125)
ABI74051	WYQQKPGQPPKLLIY (SEQ ID NO:126)
CAC39383	PKLLIYAASS (SEQ ID NO:127)
CAA38592	SVDS (SEQ ID NO:128)
AAK26833	DSGVPSRFSGSGSGT (SEQ ID NO:129)
AAM46660	RFSGSGSGTDFTLTINSLE (SEQ ID NO:130)
AAA58912	TINSLEAEDAATYFC (SEQ ID NO:136)
AAK68016	AMYFCQQ (SEQ ID NO:132)
CAK50767	SR
AAP23227	RVPYTFG (SEQ ID NO:133)
Human J2	YTFGQGTKLEIK (SEQ ID NO:104)

(c)

Table 3. Derivation of Human Sequence Segments that Comprise the Anti-PD-L2 Composite, Human Antibodies

Genbank Accession No.	VH2 Sequence
ABF83419	QVQLVQSGAEVKKPGASVK (SEQ ID NO:137)
AAG00910	MSCKASGY (SEQ ID NO:108)
ABF83419	SCKASGYTFTGY (SEQ ID NO:138)
AAL17955	TMHWV (SEQ ID NO:139)
CAC43594	WVKQ (SEQ ID NO:111)
AAL17955	QAPG (SEQ ID NO:140)
AAF40162	GQGLEWIG (SEQ ID NO:141)
AAR02558	GYINP (SEQ ID NO:142)
AAR32283	INPRSG (SEQ ID NO:143)
AAR02553	GYT
CAC87219	TEYN (SEQ ID NO:89)
AAT96419	QKF
AAA17939	KDR
AAB06403	RTT
AAA17939	TLT
AAG30529	TADKSTSTAYMELSSLRSED TAVYYCAR (SEQ ID NO:91)
ABE66740	DTAVYYCARPW (SEQ ID NO:144)
ABK81281	WFAYWGQGT (SEQ ID NO:145)
IGHJ4	YWGQGT LVT VSS (SEQ ID NO:146)

(a)

Genbank Accession No.	VH4 Sequence
ABF83419	QVQLVQSGAEVKKPGASVKV SCKASGYTFTGY (SEQ ID NO:147)
AAL17955	TMHWVRQAPG (SEQ ID NO:148)
AAF40162	GQGLEWIG (SEQ ID NO:141)
AAR02558	GYINP (SEQ ID NO:142)
AAR32283	INPRSG (SEQ ID NO:143)
AAR02553	GYT
CAC87219	TEYN (SEQ ID NO:89)
AAT96419	QKF
AAA17939	KDR
AAB06403	RTT
AAA17939	TLT
AAG30529	TADKSTSTAYMELSSLRSED TAVYYCAR (SEQ ID NO:91)
ABE66740	DTAVYYCARPW (SEQ ID NO:144)
ABK81281	WFAYWGQGT (SEQ ID NO:145)
IGHJ4	YWGQGT LVT VSS (SEQ ID NO:146)

(b)

Table 3 cont.:

Genbank Accession No.	Vκ2 Sequence
AAD16249	DIVMTQSP (SEQ ID NO:149)
CAA31193	PASL (SEQ ID NO:150)
AAA58913	LSVTPGEKVTITC (SEQ ID NO:151)
AAQ99244	CKSSQSL (SEQ ID NO:152)
ABA71421	LNS
AAD19451	GN
AAS86065	QK
AAD14073	KNYLTWYQQKPGQPPKLLIYWASTRESGVPDRF (SEQ ID NO:153)
AAZ09126	RFTGSGSGTDFLTITSLQAEDVAVYYCQ (SEQ ID NO:154)
CAA31484	NDY
CAC87582	YSYPL (SEQ ID NO:155)
human J1	TFGQGTEKLEIK (SEQ ID NO:156)

(c)

Genbank Accession No.	Vκ3 Sequence
AAD16249	DIVMTQSP (SEQ ID NO:149)
AAA58913	VMTQSPAFLSVTPGEKVTITC (SEQ ID NO:157)
AAQ99244	CKSSQSL (SEQ ID NO:152)
ABA71421	LNS
AAD19451	GN
AAS86065	QK
AAD14073	KNYLTWYQQKPGQPPKLLIYWASTRESGVPDRF (SEQ ID NO:153)
AAZ09126	RFTGSGSGTDFLTITSLQAEDVAVYYCQ (SEQ ID NO:154)
CAA31484	NDY
CAC87582	YSYPL (SEQ ID NO:155)
human J1	TFGQGTEKLEIK (SEQ ID NO:156)

(d)

Genbank Accession No.	Vκ4 Sequence
AAD16249	DIVMTQSP (SEQ ID NO:149)
AAA58913	VMTQSPAFLSVTPGEKVTITC (SEQ ID NO:157)
AAQ99244	CKSSQSL (SEQ ID NO:152)
ABA71421	LNS
AAD19451	GN
AAS86065	QK
AAD14073	KNYLTWYQQKPGQPPKLLIYWASTRESGVPDRF (SEQ ID NO:153)
CAD44754	RFTGSGSGTDFLTITSLQAEDVAVYYCQ (SEQ ID NO:158)
CAA31484	NDY
CAC87582	YSYPL (SEQ ID NO:155)
human J1	TFGQGTEKLEIK (SEQ ID NO:156)

(e)

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Example 2: Generation and Testing of Composite, Human Antibodies

- [0257] Initial variant 1 composite, human antibody VH and VK region genes were synthesized for EH12.2H7, 29E.2A3 and 24F.10C12 using a series of overlapping oligonucleotides that were annealed, ligated and PCR amplified to give full length synthetic V-regions (Figure 2A, Figure 3A, Figure 4A, Figure 5A, Figure 6A and Figure 7A). For each composite, human antibody, subsequent sequence variants were constructed using long overlapping oligonucleotides and PCR, using the initial variant 1 as the template. The assembled variants were then cloned directly into expression vectors (Figure 1) and their sequences were verified.
- [0258] All combinations of chimeric and composite heavy and light chains (*i.e.* a total of 20 pairings for each antibody) were stably transfected into NS0 cells by electroporation and selected in media (high glucose DMEM with L-glutamine and Na pyruvate, 5% ultra-low IgG FCS, pen/strep – all from Invitrogen) containing 200nM methotrexate. Several drug resistant colonies for each construct were tested for expression levels and the best expressing lines were selected and frozen under liquid nitrogen.
- [0259] Supernatants from the best expressing lines for each combination were quantified using an Fc capture, Kappa light chain detection ELISA in comparison to a IgG1/kappa standard. The quantified supernatants were then tested in a competition ELISA for binding to their target antigen. Ninety-six well Maxisorb™ plates (Nunc) were coated overnight at 4°C with 50µl/well of 1 µg/ml human Fc-PD-1, Fc-PD-L1 or Fc-PD-L2 (R&D systems) in carbonate buffer pH 9.6. Duplicate titrations of mouse reference antibody and composite, human antibody samples were generated (in the range 0.0078 µg/ml to 8 µg/ml) and mixed with a constant concentration (40 ng/ml) of biotinylated mouse reference antibody in PBS pH 7.4/2% BSA. The titrations, 100 µl/well, were added to washed (4x with PBS pH 7.4/0.05% Tween 20™) assay plates and incubated at room temperature for 1 hour. Plates were washed as above and 100 µl/well of a 1/1000 dilution of streptavidin HRP (Sigma) in PBS pH 7.4/2% BSA was added and incubated for a further 1 hour at room temperature. After a further wash, bound biotinylated reference antibody was detected with 100 µl/well OPD substrate. Absorbance was measured at 490nm and the binding curves of the test antibodies were compared to the mouse reference standard. Absorbance was plotted against sample concentration and straight lines were fitted through each of the data sets. The equations of the lines were used to calculate the concentration required to inhibit Biotin-EH12.2H7 binding to PD-1, Biotin-29E.2A3 binding to PD-L1 and Biotin-24F.10C12 binding to human PD-L2 by 50% (IC₅₀).

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[0260] The antibodies with the best IC_{50} were selected and cell lines for all these variants of EH12.2H7, 29E.2A3 and 24F.10C12 antibodies were bulked up to 100 ml and grown to saturation. Antibodies were purified from each culture via protein A affinity chromatography. Briefly, supernatants were pH adjusted with 0.1 volume of 10x PBS pH 7.4 and passed over 1ml Mab Select
5 Sure™ protein A columns (GE Healthcare). The columns were washed with 10 volumes of PBS pH 7.4 before elution with 50mM citrate buffer pH 3.0. 1 ml fractions were collected and immediately neutralized with 0.1 ml of 1m Tris-HCl pH 9.0. Protein containing fractions (as judged by absorbance at 280nm) were pooled, buffer exchanged into PBS pH 7.4 and the purified antibodies stored at +4°C. Figures 8A-C shows a SDS-PAGE gel of 1µg of each antibody, stained with
10 coomassie blue. The concentrations of the antibodies were calculated by UV absorption based upon calculated molar extinction coefficients such that $E_{0.1\%}$ at 280nm = 1.61 for EH12.2H7, $E_{0.1\%}$ at 280nm = 1.46 for 29E.2A3 and $E_{0.1\%}$ at 280nm = 1.57 for 24F.10C12.

[0261] The purified antibodies were tested for binding to human Fc-PD-1, Fc-PD-L1 or Fc-PD-L2 via competition ELISA as described above. Titrations of the test antibodies were done
15 from 0.0625 µg/ml to 8.0 µg/ml in duplicate. Absorbance at 490nm was measured and this was plotted against test antibody concentration (Figures 9A-C, 10A-C).

[0262] Table 4 summarizes the results for the combinations of the composite VH and VK variant sequences for the anti-PD-1, PD-L1 and PD-L2 antibodies. For EH12.2H7 all the humanized antibodies have an IC_{50} that is improved compared to the mouse reference, particularly VH4/VK3 that
20 has a two-fold increase in binding. In the case of 29E.2A3, variants VH2/VK1 and VH2/VK4 have equivalent binding to the mouse reference whereas variants VH2/VK2 and VH4/VK2 have reduced binding by 1.75 and 1.36 fold respectively. For 24F.10C12, all selected variants have similar, but slightly reduced, binding compared to the mouse reference (1.13 fold).

Table 4: IC50 Values for PD-1, PD-L1 and PD-L2 Composite, human Antibody Sequence Variants

EH12.2H7		29E.2A3		24F.10C12	
Antibody	IC50 μ g/ml	Antibody	IC50 μ g/ml	Antibody	IC50 μ g/ml
mouse	1.23	mouse	0.28	mouse	0.52
VH3/VK3	0.93	VH2/VK1	0.27	VH2/VK2	0.58
VH3/VK4	0.74	VH2/VK2	0.49	VH2/VK3	0.59
VH4/VK3	0.57	VH4/VK2	0.38	VH4/VK2	0.60
VH4/VK4	0.91	VH2/VK4	0.29	VH4/VK4	0.58

[0263] As a result of these experiments, composite, human antibodies specific for human PD-1, PD-L1 and PD-L2 have been constructed from amino acid sequence segments derived entirely from unrelated human antibody variable regions. All CDR and framework regions in the composite, human antibody variants comprised more than one unrelated human sequence segment (sourced from the human sequence database), and all composite, human antibodies were designed specifically to avoid T cell epitopes. Four lead candidates were initially selected for binding to human PD-1, PD-L1 or PD-L2 and, upon subsequent analysis, were demonstrated to have binding within two-fold of the murine antibody.

Example 5: Enhanced stimulation of T cell activation by inhibition of PD-1:PD-ligand interaction

[0264] The PD-1 signaling pathway inhibits moderate TCR/CD28 costimulatory signals, with cytokine production being reduced first without a decrease in T cell proliferation. As the TCR/CD28 costimulatory signals weaken, the PD-1 pathway dominates, with a great reduction in cytokine production accompanied by a reduction in proliferation. Accordingly, in order to confirm that the inhibition of the PD-1 pathway via inhibition of the interaction with PD-L1 or PD-L2 using composite, human antibodies of the invention enhances T cell activation, mixed lymphocyte reactions (MLRs) are performed.

[0265] Immature myeloid dendritic cells are isolated by culturing human peripheral blood monocytes in IL-4 and GM-CSF. Exposure of immature dendritic cells to an inflammatory cocktail

of IL-1 β , TNF- α , IL-6, and PGE₂ elicits the development of mature dendritic cells that function as APCs. However, the addition of IL-10 to the inflammatory cytokines given during the maturation phase results in APCs that function only 1/6 to 1/3 as well.

[0266] T cell activation assays (MLRs) are performed, using IL-10 treated dendritic cells as APCs, in the presence of composite, human antibodies to PD-1, PD-L1 and/or PD-L2, or control antibodies. The addition of anti-PD-1, anti-PD-L1 and/or PD-L2 mAb to cultures of IL-10 treated dendritic cells plus allogeneic T cells is predicted to result in an increase in T cell proliferation and cytokine expression, as compared to control IgG treated cultures. A combination of anti-PD-1 antibodies with anti-PD-L1 antibodies, anti-PD-L2 antibodies, may also result in an increase in stimulation greater than that seen with either antibody alone.

Example 6: Inhibition of the PD-1 Pathway in Chronically-Infected Mice

[0267] Mice infected with various strains of the lymphocytic choriomeningitis virus (LCMV) are used to study the effect of chronic viral infection on CD8 T cell function. The LCMV Armstrong strain causes an acute infection that is cleared within 8 days, leaving behind a long-lived population of highly functional, resting memory CD8 T cells. The LCMV Cl-13 strain, in contrast, establishes a persistent infection in the host, characterized by a viremia that lasts up to 3 months.

[0268] To confirm that blocking the PD-1 signaling restores T cell function and enhances viral control during chronic LCMV infection, the PD-1 signalling is disrupted during chronic LCMV infection using composite, human anti-PD-1 antibodies, anti-PD-L1 antibodies and/or anti-PD-L2 antibodies of the invention. The antibodies are administered every third day to mice infected with LCMV Cl-13 from day 23 to day 37 post-infection. It is expected that at day 37 there will be several-fold more LCMV specific CD8 T cells in treated mice relative to the untreated controls. It is also expected that the induction of proliferation will be specific to CD8 T cells since the number of CD4 T cells in the spleen will probably be approximately the same in both treated mice and untreated mice.

[0269] In addition to an increase in CD8 T cell proliferation, it is expected that the inhibition of PD-1 signaling will also result in an increased production of anti-viral cytokines in virus-specific CD8 T cells. The production of IFN-gamma and TNF-alpha by CD8 T cells will likely be several-fold higher in treated mice as compared to untreated mice. Viral clearance should also be

accelerated, and reduced viral titers should be observed in the lung and kidney by day 37 post-infection in treated mice, while untreated mice likely will display significant levels of virus in all these tissues.

[0270] CD4 T cells play a key role in the generation and maintenance of CD8 T cell responses. In this regard, CD8 T cells primed in the absence of CD4 T cells are incapable of mounting normal immune responses, and are thus often referred to as “helpless T cells.” Furthermore, chronic LCMV infection is more severe in the absence of CD4 T cells. Accordingly, helpless T cells generated during LCMV-Cl-13 infection display an even more profound functional impairment than T cells generated in the presence of CD4 T cells.

[0271] CD4 T cells are depleted at the time of LCMV-Cl-13 infection and mice are treated with composite, human anti-PD-1 antibodies, anti-PD-L1 antibodies and/or anti-PD-L1 antibodies of the present invention from day 46 to day 60 post-infection. It is expected that following treatment, treated mice likely will have several-fold more LCMV-specific CD8T cells in their spleen than untreated control mice. This increase in virus-specific CD8 T cells in treated mice likely will be the result to an increase in proliferation, as detected by BrdU incorporation. BrdU analysis is performed by introducing 1 mg/ml BrdU in the drinking water during treatment and staining is performed according to the manufacturer’s protocol (BD Biosciences, San Diego, Calif.).

[0272] To confirm that the inhibition of PD-1 signals increases the lytic activity of helpless, exhausted, virus-specific CD8 T cells, ex vivo lytic activity of virus-specific CD8 T cells is detected following treatment using a ⁵¹Cr release assay (Wherry et al., 2003. J. Virol. 77:4911-27). Viral titers are expected to be reduced by several-fold in the spleen, liver, lung, and serum after 2 weeks of treatment relative to untreated mice.

Example 7: Administration of a Vaccine with an inhibitor of PD-1 Signaling

[0273] One approach for boosting T cell responses during a persistent infection is therapeutic vaccination. The rationale for this approach is that endogenous antigens may not be presented in an optimal or immunogenic manner during chronic viral infection and that providing antigen in the form of a vaccine may provide a more effective stimulus for virus-specific T and B cells. Using the chronic LCMV model, mice are administered a recombinant vaccinia virus expressing the LCMV GP33 epitope as a therapeutic vaccine (VVGP33), which results in a modest enhancement of CD8 T

cell responses in some chronically infected mice. This therapeutic vaccination is combined with composite, human anti-PD-1 antibodies, anti-PD-L1 antibodies and/or anti-PD-L2 antibodies of the invention. It is expected that LCMV specific T cell responses will be boosted to a greater level than compared to either treatment alone and the effect of combined treatment will likely be more than additive.

Example 8: Chimpanzees as a Model for Immunotherapy of Persistent HCV Infection.

[0274] Chimpanzees provide a model of HCV persistence in humans. Defects in T cell immunity leading to life-long virus persistence both include a deficit in HCV-specific CD4 helper T cells and impaired or altered CD8 effector T cell activity. Persistently infected chimpanzees are treated with composite, human anti-PD-1 antibodies, anti-PD-L1 antibodies and/or anti-PD-L2 antibodies of the invention. The efficacy of blockade of the inhibitory pathways, combined with vaccination using recombinant structural and non-structural HCV proteins, and whether such strategies can enhance the frequency and longevity of virus-specific memory T cells are determined. The defect in T cell immunity is exclusively HCV-specific in persistently infected humans and chimpanzees. Antiviral activity may then be restored by delivering to chimpanzees humanized monoclonal antibodies that block signaling through these molecules.

[0275] Persistently infected chimpanzees are treated with composite, human anti-PD-1 antibodies, anti-PD-L1 antibodies and/or anti-PD-L2 antibodies of the invention. After treatment with antibodies, the humoral and cellular immune responses as well as the HCV RNA load are determined. Samples are collected at weeks 1, 2, 3, 5, and 8, and then at monthly intervals. Samples include: 1) serum for analysis of transaminases, autoantibodies, neutralizing antibodies to HCV, and cytokine responses, 2) plasma for viral load and genome evolution, 3) PBMC for in vitro measures of immunity, costimulatory/inhibitory receptor expression and function, 4) fresh (unfixed) liver for isolation of intrahepatic lymphocytes and RNA, and 5) fixed (formalin/paraffin embedded) liver for histology and immunohistochemical analysis. Regional lymph nodes are also collected at 2 or 3 time points to assess expression of co-inhibitory molecules and splice variants by immunohistochemistry and molecular techniques.

[0276] To determine if vaccination with HCV antigens potentiates the therapeutic effect of the antibodies, chimpanzees are treated as follows: 1) intramuscular immunization with recombinant

envelope glycoproteins E1 and E2 (in MF59 adjuvant) and other proteins (core plus NS 3, 4, and 5 formulated with ISCOMS) at weeks 0, 4, and 24; 2) intramuscular immunization with the vaccine used in, but co-administered with composite, human anti-PD-1 antibodies, anti-PD-L1 antibodies and/or anti-PD-L2 antibodies of the invention antibodies. HCV-specific T and B cell responses are monitored at monthly intervals after immunization for a period of 1 year.

[0277] Markers examined on HCV-tetramer positive and total T cells in this analysis include markers of differentiation (e.g. CD45RA/RO, CD62L, CCR7, and CD27), activation (e.g. CD25, CD69, CD38, and HLA-DR), survival/proliferation (e.g. bcl-2 and Ki67), cytotoxic potential (e.g. granzymes and perforin), and cytokine receptors (CD122 and CD127). An interesting correlation exists between pre-therapy levels of the chemokine IP-10 and response to PEG IFN- γ /ribavirin. IP-10 levels are measured to investigate a potential correlation between negative regulatory pathways or HCV-specific T cell responses and IP-10 levels. Expression of inhibitory receptors and ligands on PBMC are performed by flow cytometry.

Example 9: Enhancing SIV-specific immunity in vivo by PD-1 blockade

[0278] Immune restoration potential of blockade of PD-1 during chronic simian immunodeficiency virus (SIV) infection was tested in macaques. Fourteen Indian rhesus macaques (*Macaca mulatta*) infected with SIV were studied. Eight macaques were used for the early chronic phase and were infected intravenously with 200 50% tissue culture infectious dose (TCID₅₀) of SIV251. Six macaques were used for the late chronic phase, three were infected with SIV251 intrarectally and three were infected with SIV239 intravenously. All macaques, except RDb11, were negative for Mamu B08 and Mamu B17 alleles. RDb11 was positive for Mamu B17 allele.

[0279] In vivo antibody treatment: Macaques were infused with either partially humanized mouse anti-human PD-1 antibody (clone EH12-1540) (Dorfman et al., Am. J. Surg. Pathol. 30:802-810, 2006) or a control antibody (SYNAGIS). The anti-PD-1 antibody has mouse variable heavy chain domain linked to human IgG1 (mutated to reduce FcR and complement binding) and mouse variable light chain domain linked to human κ . The clone EH12 binds to macaque PD-1 and blocks interactions between PD-1 and its ligands in vitro. SYNAGIS is a humanized mouse monoclonal antibody (IgG1 κ) specific to F protein of respiratory syncytial virus. Antibodies were administered intravenously at 3 mg kg⁻¹ of body weight on days 0, 3, 7 and 10.

[0280] Immune responses: Peripheral blood mononuclear cells from blood and lymphocytes from rectal pinch biopsies were isolated as described previously (Velu et al., J. Virol. 81:5819-5828, 2007). Tetramer staining, intracellular cytokine production, and measurements of anti-SIV Env binding antibody were performed as described previously (Amara et al, Science 292:69-74, 2001; Kannanganat et al., J. Virol. 81:8468-8476, 2007; Lai et al., Virology 369:153-167, 2007).

[0281] PD-1 blockade was performed during the early (10 weeks) as well as late (about 90 weeks) phases of chronic SIV infection. Nine macaques (five during the early phase and four during the late phase) received the anti-PD-1 antibody and five macaques (three during the early phase and two during the late phase) received an isotype control antibody (Synagis, anti-respiratory syncytial virus (RSV)-specific).

[0282] PD-1 blockade during chronic SIV infection resulted in a rapid expansion of SIV-specific CD8 T cells in the blood of all macaques. The CD8 T-cell responses to two immunodominant epitopes, Gag CM9 (Allen et al., J. Immunol. 160:6062-6071, 1998) and Tat SL8/TL8 (Allen et al., Nature 407:386-390, 2000), were studied using major histocompatibility complex (MHC) I tetrameric complexes in seven of the anti-PD-1-antibody-treated and three of the control-antibody-treated macaques that expressed the Mamu A*01 histocompatibility molecule. Most (>98%) of the Gag-CM9 tetramer-specific CD8 T cells expressed PD-1 before blockade. After PD-1 blockade, the Gag-CM9 tetramer-specific CD8 T cells expanded rapidly and peaked by 7-21 days. At the peak response, these levels were about 2.5 to 11-fold higher than their respective levels on day 0 ($P = 0.007$) and remained elevated until 28-45 days. Similar results were observed with blockade during the early as well as late phases of chronic SIV infection. A 3-4-fold increase in the frequency of Gag-specific interferon (IFN)- γ -positive CD8 T cells was also observed by day 14 after blockade in the two Mamu A*01-negative animals (RTd11 and RDb11), demonstrating that PD-1 blockade can enhance the frequency of virus-specific CD8 T cells that are restricted by non-Mamu A*01 alleles. Expansion of SIV-specific CD8 T cells was not observed in the control-antibody treated macaques.

[0283] PD-1 blockade was also associated with a significant increase in the frequency of virus-specific CD8 T cells that were undergoing active cell division in vivo with improved functional quality. Consistent with the rapid expansion of SIV-specific CD8 T cells, the frequency of Gag-CM9 tetramer-specific CD8 cells that co-expressed Ki67 (marker for proliferating cells) also increased as early as by day 7 after blockade ($P = 0.01$). Similarly, we observed an increase in the

frequencies of Gag-CM9 tetramer-specific CD8 T cells co-expressing perforin and granzyme B (cytolytic potential; $P=0.001$ and $P=0.03$, respectively), CD28 (co-stimulation potential; $P=0.001$), CD127 (proliferative potential; $P=0.0003$) and CCR7 (lymph-node homing potential; $P=0.001$). A transient 1.5 to 2-fold increase in the frequency of tetramer-negative and Ki67-positive CD8 T cells after blockade was observed. This could be due to expansion of CD8 T cells specific to other epitopes in Gag as well as other proteins of SIV, and other chronic viral infections in these animals. No significant enhancement was observed for these markers in the three control antibody-treated macaques.

[0284] No expansion was observed for Tat-TL8-specific CD8 T cells after blockade. This could be due to viral escape from recognition by Tat-TL8-specific CD8 T cells, as PD-1 blockade is known to result in expansion of T cells only when they simultaneously receive signals through T-cell receptor. To test this possibility, the viral genomes present in the plasma just before the initiation of blockade from all three Mamu A*01- positive macaques that were infected with SIV251 and received the blocking antibody during the early phase of infection were sequenced. Indeed, mutations in the viral genome corresponding to the Tat TL8 epitope region were found. All these mutations either have been shown or predicted to reduce the binding of Tat SL8/TL8 peptide to Mamu A*01 MHC molecule and result in escape from recognition by the Tat-SL8/TL8-specific CD8 T cells". These results suggest that in vivo blockade of PD-1 may not result in expansion of T cells that are specific to escape mutants of viral epitopes.

[0285] PD-1 blockade also resulted in expansion of Gag-CM9-specific CD8 T cells at the colorectal mucosal tissue (gut), a preferential site of SIV/HIV replication. Expansion was not observed for two of the seven macaques, although expansion was evident for one of them in blood. In contrast to blood, the expansion in gut peaked much later by day 42 and ranged from 2- to 3-fold compared with their respective day 0 levels ($P=0.003$). Similar to blood, the Gag-CM9 tetramer-specific cells that co-expressed Ki67 ($P=0.01$), perforin ($P=0.03$), granzyme B ($P=0.01$) and CD28 ($P=0.01$) also increased in the gut after blockade.

[0286] More importantly, PD-1 blockade also enhanced the functional quality of anti-viral CD8 T cells and resulted in the generation of polyfunctional cells capable of co-producing the cytokines IFN- γ , tumour-necrosis factor (TNF)- α and interleukin (IL)-2. On the day of initiation of PD-1 blockade during the late chronic phase of infection, the frequency of Gag-specific IFN- γ -positive

cells was low and they failed to co-express TNF- α and IL-2. However, after the blockade, the frequency of IFN- γ -positive cells increased in all four PD-1 antibody-treated macaques ($P = 0.03$) and they acquired the ability to co-express TNF- α and IL-2. The expansion of IFN- γ positive cells peaked by 14-21 days and the peak levels were 2-10-fold higher than the respective day 0 levels. On day 21, about 16% of the total Gag-specific cells co-expressed all three cytokines, and about 30% co-expressed IFN- γ and TNF- α . This is in contrast to <1% of the total Gag-specific cells co-expressing all three cytokines ($P = 0.01$), and about 14% co-expressing IFN- γ and TNF- α on day 0 ($P = 0.04$). Similar results were also observed after blockade during the early chronic phase of infection.

[0287] To test the role of PD-1 in regulating B-cell function during chronic immunodeficiency virus infections, the B-cell responses after PD-1 blockade in SIV-infected macaques were characterized. Analysis of PD-1 expression on different B-cell subsets before PD-1 blockade revealed preferential expression of PD-1 by memory B cells ($CD20^+CD27^+CD21^-$) compared to naive B cells ($CD20^+CD27^-CD21^+$; $P < 0.001$). In vivo blockade of PD-1 resulted in a 2 to 8-fold increase in the titer of SIV-specific binding antibody by day 28 after blockade ($P < 0.001$). To understand this further, experiments were carried out to the proliferation of memory B cells in SIV-infected macaques that were treated simultaneously with anti-PD-1 antibody and anti-retroviral therapy and observed a significant increase in Ki67+ (proliferating) memory, but not naive, B cells as early as day 3. These results demonstrate that the PD-1-PDL pathway could have a role in regulating B-cell dysfunction during chronic SIV infection.

[0288] Neutralization assays revealed a two-fold increase in titers against the easily neutralizable laboratory-adapted SIV251 and no increase in titers against hard-to-neutralize wild-type SIV251 or SIV239. In two of the nine animals treated with anti-PD-1 antibody, only a minimal (<2-fold) expansion of SIV-specific antibody after blockade. Notably, the frequency of total memory B cells in these two animals was lower (-40% of total B cells) compared with the remaining seven animals (60-90% of total B cells) before blockade, indicating that the level of SIV-specific memory B cells before blockade may determine the level of expansion of SIV-specific antibody after blockade.

[0289] PD-1 blockade resulted in significant reductions in plasma viraemia ($P = 0.03$) and also prolonged the survival of SW-infected macaques ($P = 0.001$). In two of the five macaques treated with anti-PD-1 antibody during the early chronic phase, viral load declined by day 10 and persisted

at or below this level until day 90. In one macaque viral load declined transiently and in the remaining two macaques increased transiently and returned to pre-blockade levels. In contrast to the early chronic phase, all four macaques treated with the anti-PD-1 antibody during the late chronic phase showed a transient increase in viraemia by day 7, but rapidly reduced the virus load by day 21 to levels that were below their respective day 0 levels. However, the viral RNA levels returned to pre-blockade levels by day 43. As expected, no significant reductions in the plasma viral loads were observed in any of the five macaques treated with the control antibody. By 21-28 days after blockade, the viral RNA levels in the anti-PD-1-antibody-treated animals were 2-10-fold lower than their respective day 0 levels ($P = 0.03$). By day 150 after the blockade, four of the five macaques in the control group were killed owing to AIDS-related symptoms (for example loss of appetite, diarrhoea, weight loss), whereas all nine animals in the anti-PD-1-antibody-treated group had survived ($P = 0.001$).

[0290] The observed initial rise in plasma viraemia levels in all of the late phase-treated and some of the early-phase-treated animals could be due to an increase in the frequency of activated CD4 T cells. To determine this, the percentage of Ki67-positive total CD4 T cells as well as the frequency of SIV Gag-specific IFN- γ producing CD4 T cells (preferential targets for virus replication”) after blockade were measured. These analyses revealed a transient increase in the percentage of Ki67-positive CD4 T cells by day 7-14 after blockade ($P = 0.002$) and this increase was higher in animals treated during the late phase than early phase of infection ($P = 0.015$). Similarly, an increase in the frequency of Gag-specific CD4 T cells was also observed, but only in animals treated during the late phase of infection. No significant increases were observed for these activated CD4 T cells in the control-antibody-treated macaques. These results suggest that the activated CD4 T cells could have contributed to the observed initial rise in plasma viraemia levels after blockade.

[0291] Before initiation of PD-1 blockade, the set point viral load in plasma and total CD4 T cells in blood and gut were similar between the anti-PD-1-antibody-treated and control-antibody treated groups. However, the frequencies of Gag CM9+ cells and Gag CM9+ cells co-expressing perforin, granzyme B or CD28 were not similar between the two treatment groups before in vivo blockade. This raises the possibility that these differences could have contributed to the expansion of Gag CM9+ cells after PD-1 blockade. To study the influence of the frequency of Gag CM9+ cells before blockade on their expansion after blockade, the anti-PD-1-antibody-treated group into was divided

into two subgroups based on the frequency of Gag CM9+ cells before initiation of blockade such that one group has similar levels and the other group has higher levels of Gag CM9+ cells compared with the control-antibody-treated group. These subgroups were then analyzed for expansion of Gag CM9+ cells after blockade. Expansion of Gag CM9+ cells was evident in both subgroups of animals after blockade of PD-1, irrespective of whether they were at low or high levels before blockade. Similar results were also observed with subgroup analyses based on the frequency of Gag CM9+ cells co-expressing molecules associated with better T-cell function such as perforin, granzyme B, CCR7, CD 127 or CD28. However, a trend towards better expansion of Gag CM9+CD28+ cells in animals with higher levels of Gag CM9+CD28+ cells before blockade was observed, suggesting that CD28 expression may serve as a biomarker for predicting the outcome of in vivo PD-1 blockade.

[0292] The experiments described above demonstrate that PD-1 blockade using an antibody to PD-1 results in rapid expansion of virus-specific CD8 T cells with improved functional quality. This enhanced T-cell immunity was seen in the blood and also in the gut, a major reservoir of SIV infection. PD-1 blockade also resulted in proliferation of memory B cells and increases in SIV envelope-specific antibody. These improved immune responses were associated with significant reductions in plasma viral load and also prolonged the survival of SIV-infected macaques. Blockade was effective during the early (week 10) as well as late (~week 90) phases of chronic infection even under conditions of severe lymphopenia. These results demonstrate enhancement of both cellular and humoral immune responses during a pathogenic immunodeficiency virus infection by blocking a single inhibitory pathway and identify a novel therapeutic approach for control of human immunodeficiency virus infections.

Example 10: Enhanced proliferation of SIV-specific CD8 T cells following in vitro blockade of the PD-1:PDL pathway by a humanized PD-1 antibody and a humanized PD-L1 antibody

[0293] Effect of a humanized anti-PD-1 antibody derived from EH-12.2H7 and a humanized anti-PD-L1 antibody derived from 29E.2A3 on the proliferative capacity of SIV Gag-specific CD8 T cells was tested *in vitro*. The humanized anti-PD-1 antibody has the heavy chain variable region sequence of SEQ ID NO:28, and the light chain variable region sequence of SEQ ID NO:32. The humanized anti-PD-L1 antibody has the heavy chain variable region sequence of SEQ ID NO:35,

and the light chain variable region sequence of SEQ ID NO:42. The heavy chain constant region of the humanized antibodies is from human IgG4 with Ser 228 to Pro mutation (from CPSCP to CPPCP) so that the antibody forms dimers, and the light chain constant region is human kappa light chain constant region. The amino acid numbering for Ser 228 is according to the EU numbering system. See Aalberse et al., *Immunology* 105:9-19, 2002. PBMC obtained from SIV-infected macaques (between 3 months to 1.5 years after infection) were stained with carboxyfluorescein diacetate succinimidyl ester (CFSE) and stimulated either with SIV Gag peptide pool or culture medium for 6 days in the presence or absence of a blocking antibody. At the end of stimulation, cells were stained for surface CD3 and CD8, and intracellular Ki-67. Cells were then acquired on a FACS Calibur and analyzed using Flowjo software. Lymphocytes were identified based on the scatter, then CD8 T cells (CD3+, CD8+) were analyzed for co-staining for Ki-67 and CFSE. Ki-67+, CFSE low cells were identified as proliferating cells.

[0294] As shown in Figure 14A, *in vitro* blockade of PD-1:PD-1 ligand pathway using the anti-PD-1 Ab results in a significant increase in proliferation of SIV-specific CD8 T cells responses. *In vitro* blockade using the anti-PD-L1 Ab results in a modest increase in proliferation of SIV-specific CD8 T cells responses (Figure 14B).

Example 11: Restoration of HCV-specific T cell proliferation by intrahepatic mononuclear cells from a persistently infected chimpanzee

[0295] CFSE-labeled intrahepatic lymphocytes (2×10^6) were isolated from chimpanzee 1564 that had been chronically infected with the genotype 1a H77 strain of HCV for more than 10 years. The intrahepatic lymphocytes were co-cultured for 6 days with 4×10^6 irradiated autologous CD8-depleted PBMC that were either unmanipulated or pulsed with overlapping peptides spanning the entire HCV polyprotein (genotype 1a H77 strain). Cells were cultured in RPMI media supplemented with L-glutamine and 10% FCS, with and without an anti-PD-L1 blocking antibody (10 μ g/ml, added at day 0 and day 2). The humanized anti-PD-L1 antibody has the heavy chain variable region sequence of SEQ ID NO:35, and the light chain variable region sequence of SEQ ID NO:42. The heavy chain constant region of the humanized antibodies is from human IgG4 with Ser 228 to Pro mutation (from CPSCP to CPPCP) so that the antibody forms dimers, and the light chain constant region is human kappa light chain constant region. The amino acid numbering for Ser 228

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is according to the EU numbering system. See Aalberse et al., *Immunology* 105:9-19, 2002. On day 6, cells were stained with CD8-PerCP, A0701/P7(758)-PE tetramer, PD-1-Alexa 647, CD4-Alexa 700, CD14-Alexa 700, CD16-Alexa 700, CD19-Alexa 700, and Live/Dead Blue. Samples were acquired on a BD LSR II flow cytometer, and data was analyzed using FlowJo software.

- 5 [0296] As shown in Figure 15, the anti-PD-L1 antibody treatment restored HCV-specific T cell proliferation by intrahepatic mononuclear cells from a persistently infected chimpanzee.

Incorporation by Reference

[0297] In case of conflict with the publications, patents, and patent applications mentioned herein, the present application, including any definitions herein, will control.

10 Equivalents

[0298] Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, many equivalents to the specific embodiments of the invention described herein. Such equivalents are intended to be encompassed by the following claims.

SEQUENCE LISTING IN ELECTRONIC FORM

- 15 In accordance with Section 111(1) of the Patent Rules, this description contains a sequence listing in electronic form in ASCII text format (file: 69790-97 Seq 06-JUN-11 v1.txt).

A copy of the sequence listing in electronic form is available from the Canadian Intellectual Property Office.

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CLAIMS:

1. An isolated antibody or an antigen-binding fragment thereof, comprising:
 - a) a heavy chain variable region comprising the three CDR sequences of SEQ ID NOs: 13-15; and
 - 5 b) a light chain variable region comprising the three CDR sequences of SEQ ID NOs: 16-18,

wherein the isolated antibody, or the antigen-binding fragment thereof, specifically binds to a PD-L1 protein having the amino acid sequence of SEQ ID NO: 4, and the isolated antibody, or the antigen-binding fragment thereof, is chimeric, humanized, composite, or human.
- 10 2. The isolated antibody or antigen-binding fragment of claim 1, wherein the isolated antibody comprises:
 - a) a heavy chain variable region sequence selected from the group consisting of SEQ ID NOs: 34-38; and
 - b) a light chain variable region sequence selected from the group consisting of
 - 15 SEQ ID NOs: 39-42.
3. The isolated antibody or antigen-binding fragment of claim 2, wherein the isolated antibody comprises:
 - a) a heavy chain variable region sequence comprising SEQ ID NO: 35 or 37;
 - and
 - 20 b) a light chain variable region sequence comprising SEQ ID NO: 39, 40 or 42.
4. The isolated antibody or antigen-binding fragment of any one of claims 1-3, wherein the isolated antibody or antigen-binding fragment thereof inhibits the binding of 29E2A3 antibody to Fc-PD-L1.

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5. The isolated antibody or antigen-binding fragment of any one of claims 1-4, wherein the isolated antibody or antigen-binding fragment thereof inhibits a PD-L1-mediated signal.
6. An isolated nucleic acid encoding a polypeptide, wherein the polypeptide
- 5 comprises a sequence selected from the group consisting of SEQ ID NOs: 34-42.
7. An isolated nucleic acid encoding the antibody or antigen-binding fragment of any one of claims 1-5.
8. A vector comprising the isolated nucleic acid of claim 6 or 7.
9. A host cell comprising the nucleic acid of claim 6 or 7.
- 10 10. A host cell comprising the nucleic acid of claim 7 that produces the antibody or antigen-binding fragment encoded by the nucleic acid.
11. A nucleic acid that hybridizes, under stringent conditions, with the complement of a nucleic acid encoding a polypeptide selected from the group consisting of SEQ ID NOs: 34-42, wherein the stringent hybridization conditions comprise hybridization in 4x
- 15 or 6x sodium chloride/sodium citrate (SSC), at 65-70°C followed by one or more washes in 1x SSC, at 65-70°C; hybridization in 4x SSC plus 50% formamide, at 42-50°C followed by one or more washes in 1x SSC, at 65-70°C; includes hybridization at 6x SSC at 45°C, followed by one or more washes in 0.2x SSC and 0.1% SDS at 65°C; hybridization in 1x SSC, at 65-70°C followed by one or more washes in 0.3x SSC, at 65-70°C; or hybridization in 1x SSC plus 50%
- 20 formamide, at 42-50°C followed by one or more washes in 0.3x SSC, at 65-70°C.
12. A pharmaceutical composition, comprising the isolated antibody or antigen-binding fragment of any one of claims 1-5 and a pharmaceutically acceptable carrier.
13. A composition comprising an antibody, or an antigen-binding fragment thereof, of any one of claims 1-5 and a pharmaceutically-acceptable carrier, in an effective
- 25 amount for use in reactivating exhausted T cells in a population of T cells, wherein at least some T cells express PD-L1.

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14. The composition of claim 13, for use *in vitro*.
15. The composition of claim 13, for use *ex vivo*.
16. The composition of claim 13, for use *in vivo*.
17. A composition comprising the antibody, or antigen-binding fragment thereof,
5 of any one of claims 1-3 and a pharmaceutically-acceptable carrier, for use in treating a persistent infection in a subject.
18. A composition comprising the antibody, or an antigen-binding fragment thereof, of any one of claims 1-5 and a pharmaceutically-acceptable carrier, for use in treating a viral infection in a subject.
- 10 19. The composition of claim 18, wherein the viral infection is selected from the group consisting of cytomegalovirus, Epstein-Barr virus, hepatitis B virus, hepatitis C virus, herpes virus, human immunodeficiency virus, human T lymphotropic virus, lymphocytic choriomeningitis virus, respiratory syncytial virus, and rhinovirus.
20. A composition comprising the antibody, or antigen-binding fragment thereof,
15 of any one of claims 1-5 and a pharmaceutically-acceptable carrier, for use in treating a bacterial infection in a subject.
21. The composition of claim 20, wherein the bacterial infection is selected from the group consisting of *Helicobacter*, *Mycobacterium*, *Porphyromonas*, and *Chlamydia*.
22. A composition comprising the antibody, or antigen-binding fragment thereof,
20 of any one of claims 1-5 and a pharmaceutically-acceptable carrier, for use in treating a helminth infection in a subject.
23. The composition of claim 22, wherein the helminth is selected from the group consisting of *Schistosoma* and *Taenia*.

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24. A composition comprising the antibody, or antigen-binding fragment thereof, of any one of claims 1-5 and a pharmaceutically-acceptable carrier, for use in treating a protozoan infection in a subject.
25. The composition of claim 24, wherein the protozoan infection is selected from
5 the group consisting of *Leishmania mexicana* and *Plasmodium*.
26. A composition comprising the antibody, or antigen-binding fragment thereof, of any one of claims 1-5 and a pharmaceutically-acceptable carrier, for use in treating cancer in a subject.
27. The composition of claim 26, wherein the cancer is selected from the group
10 consisting of a solid tumor, a hematologic cancer, bladder cancer, brain cancer, breast cancer, colon cancer, gastric cancer, glioma, head cancer, leukemia, liver cancer, lung cancer, lymphoma, myeloma, neck cancer, ovarian cancer, melanoma, pancreatic cancer, renal cancer, salivary cancer, stomach cancer, thymic epithelial cancer, and thyroid cancer.
28. A composition comprising the antibody, or antigen-binding fragment thereof,
15 of any one of claims 1-5 and a pharmaceutically-acceptable carrier, for use in treating a cancer over-expressing PD-L1 in a subject.
29. The composition of claim 28, wherein the isolated antibody induces antibody-mediated cytotoxicity.
30. The composition of claim 29, wherein the antibody is modified to increase
20 antibody-induced cytotoxicity.
31. The composition of claim 30, wherein the antibody is conjugated to an agent selected from the group consisting of a toxin and an imaging agent.
32. A method of producing the antibody or antigen-binding fragment of any one of claims 1-5, comprising culturing a cell that produces the antibody or antigen-binding
25 fragment, and recovering the antibody or antigen-binding fragment from the cell culture.

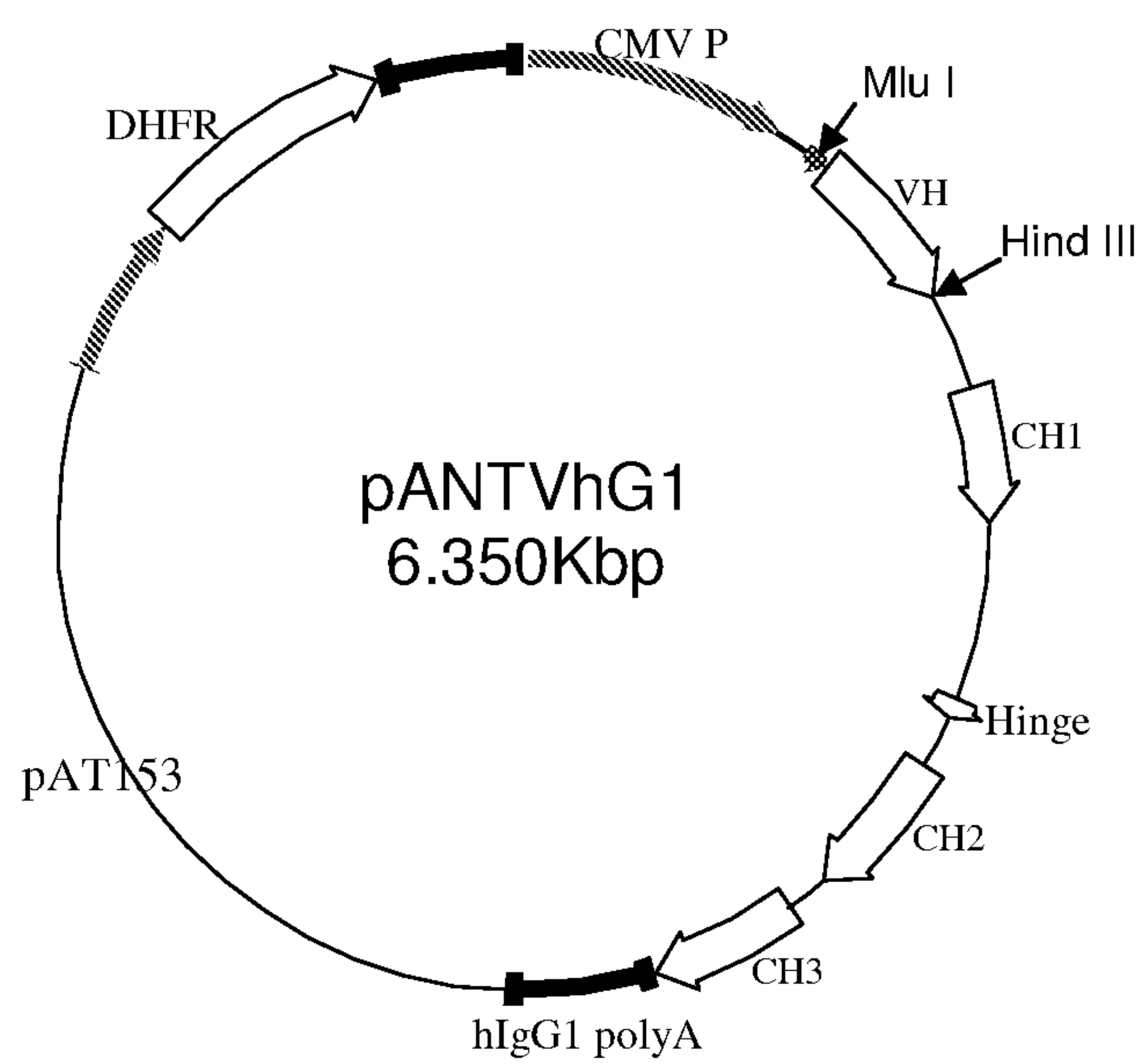
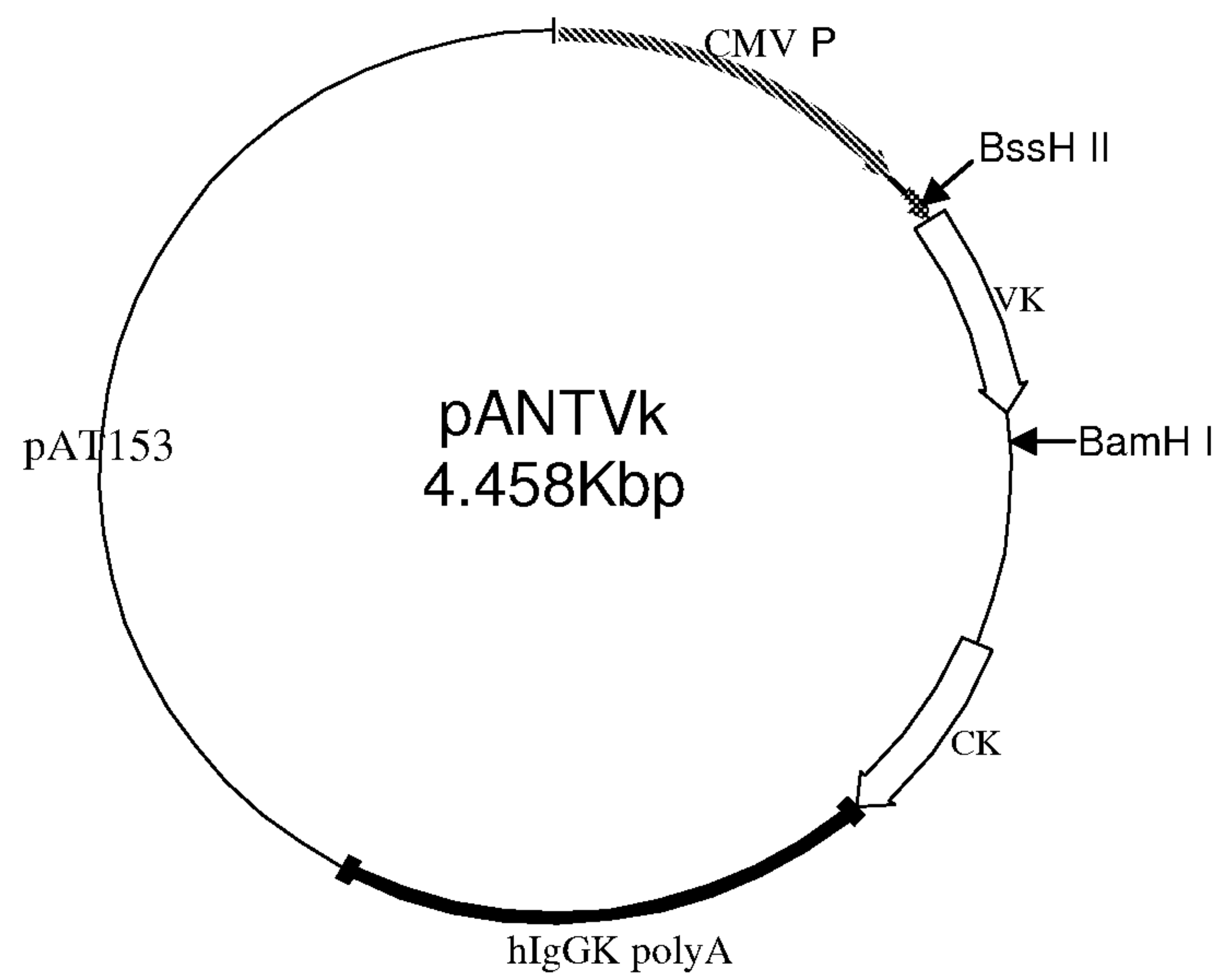
Figure 1. Expression Vector Diagrams

Figure 2: Composite, Human Antibody Sequence Variants of Anti-PD-1 Heavy Chains
(Figure 2A) Heavy chain VH1

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      10      20      30      40      50
CAGGTC CAGCTT GTGCAG TCTGGG GCTGAA CTGAAAC AGCCTG GGGGCCTC
Q  V  Q  L  V  Q  S  G  A  E  L  K  Q  P  G  A  S

      60      70      80      90     100
AGTGAAG ATGTCCTG CAAGGCTT CTGGCTAC AGTTT TACTAG CTCTCCT GGA
  V  K  M  S  C  K  A  S  G  Y  S  F  T  S  S  W
                                   CDR1

     110     120     130     140     150
TACACTG GGTGAA ACAGGCTC CTGGACAG GGTCTG GAATGG ATTGGAT AC
I  H  W  V  K  Q  A  P  G  Q  G  L  E  W  I  G  Y

     160     170     180     190     200
ATTTATC CTAGCA CTGGTTT TACTGAGT ACAATC AGAAGTT CAAGGAC AG
I  Y  P  S  T  G  F  T  E  Y  N  Q  K  F  K  D  R
                        CDR2

     210     220     230     240     250
GGCCACAT TGACTGC AGACAAAT CCACCAGC ACAGCCTA CATGGA ACTGA
  A  T  L  T  A  D  K  S  T  S  T  A  Y  M  E  L

     260     270     280     290     300
GCAGCCTG AGATCTG AGGACTCT GCAGTCTA TTACTGTG CAAGATG GAGG
S  S  L  R  S  E  D  S  A  V  Y  Y  C  A  R  W  R

     310     320     330     340     350
GACAGCTC GGGCTAC CATGCTAT GGACTACT GGGGTCA AGGAAC CTCAGT
D  S  S  G  Y  H  A  M  D  Y  W  G  Q  G  T  S  V
                        CDR3

     360
CACCGTCT CCTCA (SEQ ID NO:1)
  T  V  S  S  (SEQ ID NO:25)
```

(Figure 2B) Heavy chain VH2

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      10      20      30      40      50
CAGGTCCAGCTTGTGCAAGTCTGGGGCTGAAGTGAAACAGCCTGGGGCCTC
  Q  V  Q  L  V  Q  S  G  A  E  V  K  Q  P  G  A  S

      60      70      80      90     100
AGTGAAGATGTCCTGCAAGGCTTCTGGCTACAGTTTTACTAGCTCCTGGA
  V  K  M  S  C  K  A  S  G  Y  S  F  T  S  S  W
                                   CDR1

     110     120     130     140     150
TACACTGGGTGAAACAGGCTCCTGGACAGGGTCTGGAATGGATTGGATAC
I  H  W  V  K  Q  A  P  G  Q  G  L  E  W  I  G  Y

     160     170     180     190     200
ATTTATCCTAGCACTGGTTTTACTGAGTACAATCAGAAGTTCAAGGACAG
  I  Y  P  S  T  G  F  T  E  Y  N  Q  K  F  K  D  R
                CDR2

     210     220     230     240     250
GGCCACATTGACTGCAGACAAATCCACCAGCACAGCCTACATGGAAGTGA
  A  T  L  T  A  D  K  S  T  S  T  A  Y  M  E  L

     260     270     280     290     300
GCAGCCTGAGATCTGAGGACACTGCAGTCTATTACTGTGCAAGATGGAGG
S  S  L  R  S  E  D  T  A  V  Y  Y  C  A  R  W  R

     310     320     330     340     350
GACAGCTCGGGCTACCATGCTATGGACTACTGGGGTCAAGGAACCTCAGT
D  S  S  G  Y  H  A  M  D  Y  W  G  Q  G  T  S  V
                CDR3

     360
CACCGTCTCCTCA (SEQ ID NO:3)
  T  V  S  S  (SEQ ID NO:26)
```

(Figure 2C) Heavy chain VH3

```

      10      20      30      40      50
CAGGTCCAGCTTGTGCAGTCTGGGGCTGAAGTGAAACAGCCTGGGGCCTC
  Q  V  Q  L  V  Q  S  G  H  E  V  K  Q  P  G  A  S

      60      70      80      90     100
AGTGAAGATGTCCTGCAAGGCTTCTGGCTACAGTTTTACTAGCTCCTGGA
  V  K  M  S  C  K  A  S  G  Y  S  F  T  S  S  W
                                   CDR1

     110     120     130     140     150
TACACTGGGTGAAACAGGCTCCTGGACAGGGTCTGGAATGGATTGGATAC
I  H  W  V  K  Q  A  P  G  Q  G  L  E  W  I  G  Y

     160     170     180     190     200
ATTTATCCTAGCACTGGTTTTACTGAGTACAATCAGAAGTTCAAGGACAG
  I  Y  P  S  T  G  F  T  E  Y  N  Q  K  F  K  D  R
                CDR2

     210     220     230     240     250
GGCCACATTGACTGCAGACAAATCCACCAGCACAGCCTACATGGAAGTGA
  A  T  L  T  A  D  K  S  T  S  T  A  Y  M  E  L

     260     270     280     290     300
GCAGCCTGAGATCTGAGGACACTGCAGTCTATTACTGTGCAAGATGGAGG
S  S  L  R  S  E  D  T  A  V  Y  Y  C  A  R  W  R

     310     320     330     340     350
GACAGCTCGGGCTACCATGCTATGGACTACTGGGGTCAAGGAACCCTGGT
D  S  S  G  Y  H  A  M  D  Y  W  G  Q  G  T  L  V
                CDR3

     360
CACCGTCTCCTCA (SEQ ID NO:5)
  T  V  S  S  (SEQ ID NO:27)
```

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(Figure 2D) Heavy chain VH4

10 20 30 40 50
CAGGTCCAGCTTGTGCAGTCTGGGCATGAAGTGAAACAGCCTGGGGCCTC
Q V Q L V Q S G H E V K Q P G A S

60 70 80 90 100
AGTGAAGATGTCCTGCAAGGCTTCTGGCTACAGTTTTACTAGCTCCTGGA
V K M S C K A S G Y S F T S S W
CDR1

110 120 130 140 150
TACTACTGGGTGAGACAGGCTCCTGGACAGGGTCTGGAATGGATTGGATAC
I H W V R Q A P G Q G L E W I G Y

160 170 180 190 200
ATTTATCCTAGCACTGGTTTTACTGAGTACAATCAGAAGTTCAAGGACAG
I Y P S T G F T E Y N Q K F K D R
CDR2

210 220 230 240 250
GGCCACATTGACTGCAGACAAATCCACCAGCACAGCCTACATGGAAGTGA
A T L T A D K S T S T A Y M E L

260 270 280 290 300
GCAGCCTGAGATCTGAGGACACTGCAGTCTATTACTGTGCAAGATGGAGG
S S L R S E D T A V Y Y C A R W R

310 320 330 340 350
GACAGCTCGGGCTACCATGCTATGGACTACTGGGGTCAAGGAACCCTGGT
D S S G Y H A M D Y W G Q G T L V
CDR3

360
CACCGTCTCCTCA (SEQ ID NO:52)
T V S S (SEQ ID NO:28)

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(Figure 2E) Heavy chain VH5

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      10      20      30      40      50
CAGGTCCAGCTTGTGCAAGTCTGGGCATGAAGTGAAACAGCCTGGGGCCTC
  Q  V  Q  L  V  Q  S  G  H  E  V  K  Q  P  G  A  S

      60      70      80      90     100
AGTGAAGGTGTCCTGCAAGGCTTCTGGCTACAGTTTTACTAGCTCCTGGA
  V  K  V  S  C  K  A  S  G  Y  S  F  T  S  S  W
                                   CDR1

     110     120     130     140     150
TACACTGGGTGAGACAGGCTCCTGGACAGGGTCTGGAATGGATTGGATAC
I  H  W  V  R  Q  A  P  G  Q  G  L  E  W  I  G  Y

     160     170     180     190     200
ATTTATCCTAGCACTGGTTTTACTGAGTACAATCAGAAGTTCAAGGACAG
  I  Y  P  S  T  G  F  T  E  Y  N  Q  K  F  K  D  R
      CDR2

     210     220     230     240     250
GGCCACAATCACTGCAGACAAATCCACCAGCACAGCCTACATGGAAGTGA
  A  T  I  T  A  D  K  S  T  S  T  A  Y  M  E  L

     260     270     280     290     300
GCAGCCTGAGATCTGAGGACACTGCAGTCTATTACTGTGCAAGATGGAGG
S  S  L  R  S  E  D  T  A  V  Y  Y  C  A  R  W  R

     310     320     330     340     350
GACAGCTCGGGCTACCATGCTATGGACTACTGGGGTCAAGGAACCCTGGT
D  S  S  G  Y  H  A  M  D  Y  W  G  Q  G  T  L  V
      CDR3

     360
CACCGTCTCCTCA (SEQ ID NO:53)
  T  V  S  S  (SEQ ID NO:29)
```

Figure 3: Composite, Human Antibody Sequence Variants of Anti-PD-1 Light Chains**(Figure 3A) Light chain VK1**

```

      10      20      30      40      50
GACATTGTGCTGACACAGTCTCCTGCTTCCTTAACTCTGTCTCCAGGGCA
D I V L T Q S P A S L T L S P G Q

      60      70      80      90     100
GAGGCTCACCATCTCATGCAGGGCCAGCCAAAGTGTCTCAGTACATCTGGCT
R L T I S C R A S Q S V S T S G
              CDR1

     110     120     130     140     150
ATAGTTATATGCACTGGTACCAACAGAAACCAGACCAGTCCCCCAAACCTC
Y S Y M H W Y Q Q K P D Q S P K L

     160     170     180     190     200
CTCATCAAGTTTGGCTCCAACCTAGAATCTGGCATCCCTGCCAGGTTTCAG
L I K F G S N L E S G I P A R F S
              CDR2

     210     220     230     240     250
TGGCAGTGGGTCTGGGACAGACTTCACCCTCACCATCTCTTCTCTGGAGG
G S G S G T D F T L T I S S L E

     260     270     280     290     300
AGGAGGATTTTGCAACATATTACTGTCAGCACAGTTGGGAGATTCCGTAC
E E D F A T Y Y C Q H S W E I P Y
                      CDR3

     310     320     330
ACGTTTCGGACAGGGGACCAAGCTGGAAATAAAA (SEQ ID NO:54)
T F G Q G T K L E I K (SEQ ID NO:30)
```

(Figure 3B) Light chain VK2

10 20 30 40 50
GACATTGTGCTGACACAGTCTCCTGCTACCTTATCTCTGTCTCCAGGGCA
D I V L T Q S P A T L S L S P G Q

60 70 80 90 100
GAGGCTCACCATCTCATGCAGGGCCAGCCAAAGTGTCTCAGTACATCTGGCT
R L T I S C R A S Q S V S T S G
CDR1

110 120 130 140 150
ATAGTTATATGCACTGGTACCAACAGAAACCAGACCAGTCCCCCAAACTC
Y S Y M H W Y Q Q K P D Q S P K L

160 170 180 190 200
CTCATCAAGTTTGGCTCCAACCTAGAATCTGGCATCCCTGCCAGGTTTCAG
L I K F G S N L E S G I P A R F S
CDR2

210 220 230 240 250
TGGCAGTGGGTCTGGGACAGACTTCACCCCTCACCATCTCTTCTCTGGAGC
G S G S G T D F T L T I S S L E

260 270 280 290 300
CTGAGGATTTTGCAACATATTACTGTCAGCACAGTTGGGAGATTCCGTAC
P E D F A T Y Y C Q H S W E I P Y
CDR3

310 320 330
ACGTTTCGGACAGGGGACCAAGCTGGAAATAAAA (SEQ ID NO:55)
T F G Q G T K L E I K (SEQ ID NO:31)

(Figure 3C) Light chain VK3

10 20 30 40 50
GAGATTGTGCTGACACAGTCTCCTGCTACCTTATCTCTGTCTCCAGGGCA
E I V L T Q S P A T L S L S P G Q

60 70 80 90 100
GAGGCTCACCATCTCATGCAGGGCCAGCCAAAGTGTCTCAGTACATCTGGCT
R L T I S C R A S Q S V S T S G
CDR1

110 120 130 140 150
ATAGTTATATGCACTGGTACCAACAGAAACCAGACCAGTCCCCCAAACCTC
Y S Y M H W Y Q Q K P D Q S P K L

160 170 180 190 200
CTCATCAAGTTTGGCTCCAACCTAGAATCTGGCATCCCTGCCAGGTTTCAG
L I K F G S N L E S G I P A R F S
CDR2

210 220 230 240 250
TGGCAGTGGGTCTGGGACAGACTTCACCCCTCACCATCTCTTCTCTGGAGC
G S G S G T D F T L T I S S L E

260 270 280 290 300
CTGAGGATTTTGCAACATATTACTGTCAGCACAGTTGGGAGATTCCGTAC
P E D F A T Y Y C Q H S W E I P Y
CDR3

310 320 330
ACGTTTCGGACAGGGGACCAAGCTGGAAATAAAA (SEQ ID NO:56)
T F G Q G T K L E I K (SEQ ID NO:32)

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(Figure 3D) Light chain VK4

10 20 30 40 50
GACATTGTGCTGACACAGTCTCCTGCTACCTTATCTCTGTCTCCAGGGCA
D I V L T Q S P A T L S L S P G Q

60 70 80 90 100
GAGGCTCACCATCTCATGCAGGGCCAGCCAAAGTGTCTCAGTACATCTGGCT
R L T I S C R A S Q S V S T S G
CDR1

110 120 130 140 150
ATAGTTATATGCACTGGTACCAACAGAAACCAGACCAGTCCCCCAAACTC
Y S Y M H W Y Q Q K P D Q S P K L

160 170 180 190 200
CTCATCAAGTTTGGCTCCAACCTAGAATCTGGCATCCCTGCCAGGTTTCAG
L I K F G S N L E S G I P A R F S
CDR2

210 220 230 240 250
TGGCAGTGGGTCTGGGACAGACTTCACCCCTCACCATCTCTTCTCTGGAGC
G S G S G T D F T L T I S S L E

260 270 280 290 300
CTGAGGATTTTGCAGTGTATTACTGTCAGCACAGTTGGGAGATTCCGTAC
P E D F A V Y Y C Q H S W E I P Y
CDR3

310 320 330
ACGTTTCGGACAGGGGACCAAGCTGGAAATAAAA (SEQ ID NO:57)
T F G Q G T K L E I K (SEQ ID NO:33)

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**Figure 4: Composite, Human Antibody Sequence Variants of Anti-PD-L1 Heavy Chains
(Figure 4A) Heavy chain VH1**

```

      10      20      30      40      50
GAGGTCCAGCTGGTGCAGTCTGGACCTGAGCTGAAAAAGCCTGGGGCTTC
E  V  Q  L  V  Q  S  G  P  E  L  K  K  P  G  A  S

      60      70      80      90      100
AGTGAAGATGTCCTGCAAGGCTTCTGGATACACATTCAGCTATGTTA
V  K  M  S  C  K  A  S  G  Y  T  F  T  S  Y  V
                                   CDR1

      110     120     130     140     150
TGCACTGGGTGAAGCAGGCCCTGGGCAGCGCCTTGAGTGGATTGGATAT
M  H  W  V  K  Q  A  P  G  Q  R  L  E  W  I  G  Y

      160     170     180     190     200
GTTAATCCTTTCAATGATGGTACTAAGTACAATGAGATGTTCAAAGGCAG
V  N  P  F  N  D  G  T  K  Y  N  E  M  F  K  G  R
      CDR2

      210     220     230     240     250
GGCCACACTGACTTCAGACAAATCCACCAGCACAGCCTACATGGAGCTCA
A  T  L  T  S  D  K  S  T  S  T  A  Y  M  E  L

      260     270     280     290     300
GCAGCCTGAGGTCTGAGGACTCTGCGGTCTATTACTGTGCAAGACAGGCT
S  S  L  R  S  E  D  S  A  V  Y  Y  C  A  R  Q  A

      310     320     330     340
TGGGGTTACCCCTGGGGCCAAGGGACTCTGGTCACTGTCTCTTCT (SEQ ID NO:58)
W  G  Y  P  W  G  Q  G  T  L  V  T  V  S  S (SEQ ID NO:34)
      CDR3
```

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(Figure 4B) Heavy chain VH2

10	20	30	40	50
GAGGTCCAGCTGGTGCAGTCTGGAGCTGAGGTGAAAAAGCCTGGGGCTTC				
E V Q L V Q S G A E V K K P G A S				
60	70	80	90	100
AGTGAAGATGTCCTGCAAGGCTTCTGGATACACATTCACTAGCTATGTTA				
V K M S C K A S G Y T F T <u>S Y V</u>				
CDR1				
110	120	130	140	150
TGCACTGGGTGAAGCAGGCCCTGGGCAGCGCCTTGAGTGGATTGGATAT				
<u>M H</u> W V K Q A P G Q R L E W I G <u>Y</u>				
160	170	180	190	200
GTTAATCCTTTCAATGATGGTACTAAGTACAATGAGATGTTCAAAGGCAG				
<u>V N P F N D G T K Y N E M F K G R</u>				
CDR2				
210	220	230	240	250
GGCCACACTGACTTCAGACAAATCCACCAGCACAGCCTACATGGAGCTCA				
A T L T S D K S T S T A Y M E L				
260	270	280	290	300
GCAGCCTGAGGTCTGAGGACACTGCGGTCTATTACTGTGCAAGACAGGCT				
S S L R S E D T A V Y Y C A R <u>Q A</u>				
310	320	330	340	
TGGGGTTACCCCTGGGGCCAAGGGACTCTGGTCACTGTCTCTTCT (SEQ ID NO:59)				
<u>W G Y P</u> W G Q G T L V T V S S (SEQ ID NO:35)				
CDR3				

(Figure 4C) Heavy chain VH3

```

      10      20      30      40      50
GAGGTC CAGCTGGTGCAGTCTGGAGCTGAGGTGAAAAAGCCTGGGGCTTC
E  V  Q  L  V  Q  S  G  A  E  V  K  K  P  G  A  S

      60      70      80      90     100
AGTGAAGATGTCCTGCAAGGCTTCTGGATACACATTCACTAGCTATGTTA
V  K  M  S  C  K  A  S  G  Y  T  F  T  S  Y  V
                                   CDR1

     110     120     130     140     150
TGCACTGGGTGAGGCAGGCCCTGGGCAGCGCCTTGAGTGGATTGGATAT
M  H  W  V  R  Q  A  P  G  Q  R  L  E  W  I  G  Y

     160     170     180     190     200
GTTAATCCTTTCAATGATGGTACTAAGTACAATGAGATGTTCAAAGGCAG
V  N  P  F  N  D  G  T  K  Y  N  E  M  F  K  G  R
                                   CDR2

     210     220     230     240     250
GGCCACACTGACTTCAGACAAATCCACCAGCACAGCCTACATGGAGCTCA
A  T  L  T  S  D  K  S  T  S  T  A  Y  M  E  L

     260     270     280     290     300
GCAGCCTGAGGTCTGAGGACACTGCGGTCTATTACTGTGCAAGACAGGCT
S  S  L  R  S  E  D  T  A  V  Y  Y  C  A  R  Q  A

     310     320     330     340
TGGGGTTACCCCTGGGGCCAAGGGACTCTGGTCACTGTCTCTTCT (SEQ ID NO:60)
W  G  Y  P  W  G  Q  G  T  L  V  T  V  S  S  (SEQ ID NO:36)
CDR3
```

(Figure 4D) Heavy chain VH4

```

      10      20      30      40      50
GAGGTC CAGCTGGTGCAGTCTGGAGCTGAGGTGAAAAAGCCTGGGGCTTC
  E  V  Q  L  V  Q  S  G  A  E  V  K  K  P  G  A  S

      60      70      80      90     100
AGTGAAGGTGTCCTGCAAGGCTTCTGGATACACATTCACTAGCTATGTTA
  V  K  V  S  C  K  A  S  G  Y  T  F  T  S  Y  V
                                   CDR1

     110     120     130     140     150
TGCACTGGGTGAGGCAGGCCCTGGGCAGCGCCTTGAGTGGATTGGATAT
M  H  W  V  R  Q  A  P  G  Q  R  L  E  W  I  G  Y

     160     170     180     190     200
GTTAATCCTTTCAATGATGGTACTAAGTACAATGAGATGTTCAAAGGCAG
  V  N  P  F  N  D  G  T  K  Y  N  E  M  F  K  G  R
                                   CDR2

     210     220     230     240     250
GGCCACACTGACTTCAGACAAATCCACCAGCACAGCCTACATGGAGCTCA
  A  T  L  T  S  D  K  S  T  S  T  A  Y  M  E  L

     260     270     280     290     300
GCAGCCTGAGGTCTGAGGACACTGCGGTCTATTACTGTGCAAGACAGGCT
  S  S  L  R  S  E  D  T  A  V  Y  Y  C  A  R  Q  A

     310     320     330     340
TGGGGTTACCCCTGGGGCCAAGGGACTCTGGTCACTGTCTCTTCT (SEQ ID NO:61)
W  G  Y  P  W  G  Q  G  T  L  V  T  V  S  S (SEQ ID NO:37)
      CDR3
```

(Figure 4E) Heavy chain VH5

```

      10      20      30      40      50
GAGGTC CAGCTGGTGCAGTCTGGAGCTGAGGTGAAAAAGCCTGGGGCTTC
  E  V  Q  L  V  Q  S  G  A  E  V  K  K  P  G  A  S

      60      70      80      90     100
AGTGAAGGTGTCCTGCAAGGCTTCTGGATACACATTCAGCTATGTTA
  V  K  V  S  C  K  A  S  G  Y  T  F  T  S  Y  V
                                   CDR1

     110     120     130     140     150
TGCACTGGGTGAGGCAGGCCCTGGGCAGCGCCTTGAGTGGATTGGATAT
M  H  W  V  R  Q  A  P  G  Q  R  L  E  W  I  G  Y

     160     170     180     190     200
GTTAATCCTTTCAATGATGGTACTAAGTACAATGAGATGTTCAAAGGCAG
  V  N  P  F  N  D  G  T  K  Y  N  E  M  F  K  G  R
                                   CDR2

     210     220     230     240     250
GGCCACAATCACTTCAGACAAATCCACCAGCACAGCCTACATGGAGCTCA
  A  T  I  T  S  D  K  S  T  S  T  A  Y  M  E  L

     260     270     280     290     300
GCAGCCTGAGGTCTGAGGACACTGCGGTCTATTACTGTGCAAGACAGGCT
  S  S  L  R  S  E  D  T  A  V  Y  Y  C  A  R  Q  A

     310     320     330     340
TGGGGTTACCCCTGGGGCCAAGGGACTCTGGTCACTGTCTCTTCT (SEQ ID NO:62)
W  G  Y  P  W  G  Q  G  T  L  V  T  V  S  S  (SEQ ID NO:38)
      CDR3
```

Figure 5: Composite, Human Antibody Sequence Variants of Anti-PD-L1 Light Chains**(Figure 5A) Light chain VK1**

10	20	30	40	50
GACATTGTGCTCACCCAATCTCCAGCTTCTTTGGCTCTGTCTCCCGGGGA				
D I V L T Q S P A S L A L S P G E				
60	70	80	90	100
GAGAGCCACCCTCTCCTGCAGAGCCACTGAAAGTGTGTAATACTATGGCA				
R A T L S C <u>R A T E S V E Y Y G</u>				
CDR1				
110	120	130	140	150
CAAGTTTAGTGCAGTGGTACCAACAGAAACCAGGACAGCCACCCAAACTC				
<u>T S L V Q</u> W Y Q Q K P G Q P P K L				
160	170	180	190	200
CTCATCTATGCTGCATCCAGCGTAGATTCTGGGGTCCCTTCCAGGTTTAG				
L I Y <u>A A S S V D S</u> G V P S R F S				
CDR2				
210	220	230	240	250
TGGCAGTGGGTCTGGGACAGACTTCACCCTCACCATCAATTCTCTGGAGG				
G S G S G T D F T L T I N S L E				
260	270	280	290	300
AGGAGGATGCTGCAATGTATTTCTGTCAGCAAAGTAGGAGGGTTCCGTAC				
E E D A A M Y F C <u>Q Q S R R V P Y</u>				
CDR3				
310	320	330		
ACGTTTCGGACAGGGGACCAAGCTGGAGATAAAA (SEQ ID NO:63)				
<u>T</u> F G Q G T K L E I K (SEQ ID NO:39)				

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(Figure 5B) Light chain VK2

10 20 30 40 50
GACATTGTGCTCACCCAATCTCCAGCTACTTTGTCTCTGTCTCCCGGGGA
D I V L T Q S P A T L S L S P G E

60 70 80 90 100
GAGAGCCACCCTCTCCTGCAGAGCCACTGAAAGTGTTGAATACTATGGCA
R A T L S C R A T E S V E Y Y G
CDR1

110 120 130 140 150
CAAGTTTAGTGCAGTGGTACCAACAGAAACCAGGACAGCCACCCAAACTC
T S L V Q W Y Q Q K P G Q P P K L

160 170 180 190 200
CTCATCTATGCTGCATCCAGCGTAGATTCTGGGGTCCCTTCCAGGTTTAG
L I Y A A S S V D S G V P S R F S
CDR2

210 220 230 240 250
TGGCAGTGGGTCTGGGACAGACTTCACCCCTCACCATCAATTCTCTGGAGG
G S G S G T D F T L T I N S L E

260 270 280 290 300
CCGAGGATGCTGCAATGTATTTCTGTCAGCAAAGTAGGAGGGTTCCGTAC
A E D A A M Y F C Q Q S R R V P Y
CDR3

310 320 330
ACGTTTCGGACAGGGGACCAAGCTGGAGATAAAA (SEQ ID NO:64)
T F G Q G T K L E I K (SEQ ID NO:40)

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(Figure 5C) Light chain VK3

10 20 30 40 50
GAGATTGTGCTCACCCAATCTCCAGCTACTTTGTCTCTGTCTCCCGGGGA
E I V L T Q S P A T L S L S P G E

60 70 80 90 100
GAGAGCCACCCTCTCCTGCAGAGCCACTGAAAGTGTTGAATACTATGGCA
R A T L S C R A T E S V E Y Y G
CDR1

110 120 130 140 150
CAAGTTTAGTGCA GTGGTACCAACAGAAACCAGGACAGCCACCCAAACTC
T S L V Q W Y Q Q K P G Q P P K L

160 170 180 190 200
CTCATCTATGCTGCATCCAGCGTAGATTCTGGGGTCCCTTCCAGGTTTAG
L I Y A A S S V D S G V P S R F S
CDR2

210 220 230 240 250
TGGCAGTGGGTCTGGGACAGACTTCACCCTCACCATCAATTCTCTGGAGG
G S G S G T D F T L T I N S L E

260 270 280 290 300
CCGAGGATGCTGCAATGTATTTCTGTCAGCAAAGTAGGAGGGTTCCGTAC
A E D A A M Y F C Q Q S R R V P Y
CDR3

310 320 330
ACGTTTCGGACAGGGGACCAAGCTGGAGATAAAA (SEQ ID NO:65)
T F G Q G T K L E I K (SEQ ID NO:41)

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(Figure 5D) Light chain VK4

10 20 30 40 50
GACATTGTGCTCACCCAATCTCCAGCTACTTTGTCTCTGTCTCCCGGGGA
D I V L T Q S P A T L S L S P G E

60 70 80 90 100
GAGAGCCACCCTCTCCTGCAGAGCCACTGAAAGTGTTGAATACTATGGCA
R A T L S C R A T E S V E Y Y G
CDR1

110 120 130 140 150
CAAGTTTAGTGAGTGGTACCAACAGAAACCAGGACAGCCACCCAAACTC
T S L V Q W Y Q Q K P G Q P P K L

160 170 180 190 200
CTCATCTATGCTGCATCCAGCGTAGATTCTGGGGTCCCTTCCAGGTTTAG
L I Y A A S S V D S G V P S R F S
CDR2

210 220 230 240 250
TGGCAGTGGGTCTGGGACAGACTTCACCCTCACCATCAATTCTCTGGAGG
G S G S G T D F T L T I N S L E

260 270 280 290 300
CCGAGGATGCTGCAACCTATTTCTGTCAGCAAAGTAGGAGGGTTCCGTAC
A E D A A T Y F C Q Q S R R V P Y
CDR3

310 320 330
ACGTTTCGGACAGGGGACCAAGCTGGAGATAAAA (SEQ ID NO:66)
T F G Q G T K L E I K (SEQ ID NO:42)

Figure 6: Composite, human Antibody Sequence Variants of Anti-PD-L2 Heavy Chains**(Figure 6A) Heavy chain VH1**

```

      10      20      30      40      50
CAGGTCCAGCTGGTGCAGTCTGGAGCTGAACTGAAGAAACCTGGGGCCTC
  Q  V  Q  L  V  Q  S  G  A  E  L  K  K  P  G  A  S

      60      70      80      90     100
AGTGAAGATGTCCTGCAAGGCTTCTGGCTACACCTTTACTGGCTACACGA
  V  K  M  S  C  K  A  S  G  Y  T  F  T  G  Y  T
                                           CDR1

      110     120     130     140     150
TGCACTGGGTAAAACAGGCCCTGGACAGGGTCTGGAATGGATTGGATAC
M  H  W  V  K  Q  A  P  G  Q  G  L  E  W  I  G  Y

      160     170     180     190     200
ATTAATCCTAGAAGTGGATATACTGAGTATAATCAGAAGTTCAAGGACAG
I  N  P  R  S  G  Y  T  E  Y  N  Q  K  F  K  D  R
                        CDR2

      210     220     230     240     250
GACCACATTGACTGCAGACAAATCTACCAGCACAGCCTACATGGAAGTGA
  T  T  L  T  A  D  K  S  T  S  T  A  Y  M  E  L

      260     270     280     290     300
GCAGCCTGAGATCTGAGGACTCTGCGGTCTATTATTGTGCAAGACCCTGG
S  S  L  R  S  E  D  S  A  V  Y  Y  C  A  R  P  W

      310     320     330     340
TTTGCTTACTGGGGCCAAGGGACTCTGGTCACTGTCTCTTCA (SEQ ID NO:67)
F  A  Y  W  G  Q  G  T  L  V  T  V  S  S (SEQ ID NO:43)
CDR3
```

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(Figure 6B) Heavy chain VH2

```

      10      20      30      40      50
CAGGTC CAGCTGGTGCAGTCTGGAGCTGAAGTGAAGAAACCTGGGGCCTC
  Q  V  Q  L  V  Q  S  G  A  E  V  K  K  P  G  A  S

      60      70      80      90     100
AGTGAAGATGTCCTGCAAGGCTTCTGGCTACACCTTTACTGGCTACACGA
  V  K  M  S  C  K  A  S  G  Y  T  F  T  G  Y  T
                                           CDR1

     110     120     130     140     150
TGCACTGGGTAAAACAGGCCCTGGACAGGGTCTGGAATGGATTGGATAC
M  H  W  V  K  Q  A  P  G  Q  G  L  E  W  I  G  Y

     160     170     180     190     200
ATTAATCCTAGAAAGTGGATATACTGAGTATAATCAGAAGTTCAAGGACAG
I  N  P  R  S  G  Y  T  E  Y  N  Q  K  F  K  D  R
                        CDR2

     210     220     230     240     250
GACCACATTGACTGCAGACAAATCTACCAGCACAGCCTACATGGAAGTGA
  T  T  L  T  A  D  K  S  T  S  T  A  Y  M  E  L

     260     270     280     290     300
GCAGCCTGAGATCTGAGGACACTGCGGTCTATTATTGTGCAAGACCCTGG
  S  S  L  R  S  E  D  T  A  V  Y  Y  C  A  R  P  W

     310     320     330     340
TTTGCTTACTGGGGCCAAGGGACTCTGGTCACTGTCTCTTCA (SEQ ID NO:68)
F  A  Y  W  G  Q  G  T  L  V  T  V  S  S (SEQ ID NO:44)
CDR3
```

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(Figure 6C) Heavy chain VH3

10	20	30	40	50
CAGGTC CAGCTGGTGCAGTCTGGAGCTGAAGTGAAGAAACCTGGGGCCTC				
Q V Q L V Q S G A E V K K P G A S				
60	70	80	90	100
AGTGAAGATGTCCTGCAAGGCTTCTGGCTACACCTTTACTGGCTACACGA				
V K M S C K A S G Y T F T <u>G Y T</u>				
CDR1				
110	120	130	140	150
TGCACTGGGTAAGACAGGCCCTGGACAGGGTCTGGAATGGATTGGATAC				
<u>M H</u> W V R Q A P G Q G L E W I G <u>Y</u>				
160	170	180	190	200
ATTAATCCTAGAAAGTGGATATACTGAGTATAATCAGAAGTTCAAGGACAG				
<u>I N P R S G Y T E Y N Q K F K D R</u>				
CDR2				
210	220	230	240	250
GACCACATTGACTGCAGACAAATCTACCAGCACAGCCTACATGGAACTGA				
T T L T A D K S T S T A Y M E L				
260	270	280	290	300
GCAGCCTGAGATCTGAGGACACTGCGGTCTATTATTGTGCAAGACCCTGG				
S S L R S E D T A V Y Y C A R <u>P W</u>				
310	320	330	340	
TTTGCTTACTGGGGCCAAGGGACTCTGGTCACTGTCTCTTCA (SEQ ID NO:69)				
<u>F A Y</u> W G Q G T L V T V S S (SEQ ID NO:45)				
CDR3				

(Figure 6D) Heavy chain VH4

```

      10      20      30      40      50
CAGGTC CAGCTGGTGCAGTCTGGAGCTGAAGTGAAGAAACCTGGGGCCTC
  Q  V  Q  L  V  Q  S  G  A  E  V  K  K  P  G  A  S

      60      70      80      90     100
AGTGAAGGTGTCCTGCAAGGCTTCTGGCTACACCTTTACTGGCTACACGA
  V  K  V  S  C  K  A  S  G  Y  T  F  T  G  Y  T
                                   CDR1

     110     120     130     140     150
TGCACTGGGTAAGACAGGCCCTGGACAGGGTCTGGAATGGATTGGATAC
M  H  W  V  R  Q  A  P  G  Q  G  L  E  W  I  G  Y

     160     170     180     190     200
ATTAATCCTAGAAAGTGGATATACTGAGTATAATCAGAAGTTCAAGGACAG
I  N  P  R  S  G  Y  T  E  Y  N  Q  K  F  K  D  R
                        CDR2

     210     220     230     240     250
GACCACATTGACTGCAGACAAATCTACCAGCACAGCCTACATGGAACTGA
  T  T  L  T  A  D  K  S  T  S  T  A  Y  M  E  L

     260     270     280     290     300
GCAGCCTGAGATCTGAGGACACTGCGGTCTATTATTGTGCAAGACCCTGG
  S  S  L  R  S  E  D  T  A  V  Y  Y  C  A  R  P  W

     310     320     330     340
TTTGCTTACTGGGGCCAAGGGACTCTGGTCACTGTCTCTTCA (SEQ ID NO:70)
F  A  Y  W  G  Q  G  T  L  V  T  V  S  S (SEQ ID NO:46)
      CDR3
```

(Figure 6E) Heavy chain VH5

10	20	30	40	50
CAGGTC CAGCTGGTGCAGTCTGGAGCTGAAGTGAAGAAACCTGGGGCCTC				
Q V Q L V Q S G A E V K K P G A S				
60	70	80	90	100
AGTGAAGGTGTCCTGCAAGGCTTCTGGCTACACCTTTACTGGCTACACGA				
V K V S C K A S G Y T F T <u>G Y T</u>				
CDR1				
110	120	130	140	150
TGCACTGGGTAAGACAGGCCCTGGACAGGGTCTGGAATGGATTGGATAC				
M H W V R Q A P G Q G L E W I G <u>Y</u>				
160	170	180	190	200
ATTAATCCTAGAAAGTGGATATACTGAGTATAATCAGAAGTTCAAGGACAG				
<u>I N P R S G Y T E Y N Q K F K D R</u>				
CDR2				
210	220	230	240	250
GACCACAATCACTGCAGACAAATCTACCAGCACAGCCTACATGGAAGTGA				
T T I T A D K S T S T A Y M E L				
260	270	280	290	300
GCAGCCTGAGATCTGAGGACACTGCGGTCTATTATTGTGCAAGACCCTGG				
S S L R S E D T A V Y Y C A R <u>P W</u>				
310	320	330	340	
TTTGCTTACTGGGGCCAAGGGACTCTGGTCACTGTCTCTTCA (SEQ ID NO:71)				
<u>F A Y</u> W G Q G T L V T V S S (SEQ ID NO:47)				
CDR3				

Figure 7: Composite, human Antibody Sequence Variants of Anti-PD-L2 Light Chains**(Figure 7A) Light chain VK1**

```

      10      20      30      40      50
GACATTGTGATGACACAGTCTCCAGCCTCCCTGACTGTGACACCAGGAGA
D I V M T Q S P A S L T V T P G E

      60      70      80      90     100
GAAGGTCACTATCACCTGCAAGTCCAGTCAGAGTCTGTTAAACAGTGGAA
K V T I T C K S S Q S L L N S G
                      CDR1

     110     120     130     140     150
ATCAAAAGAACTACTTGACCTGGTACCAGCAGAAACCAGGGCAGCCTCCT
N Q K N Y L T W Y Q Q K P G Q P P

     160     170     180     190     200
AAACTGTTGATCTACTGGGCATCCACTAGGGAATCTGGGGTCCCTGATCG
K L L I Y W A S T R E S G V P D R
                      CDR2

     210     220     230     240     250
CTTCACAGGCAGTGGATCTGGAACAGATTTCACTCTCACCATCAGCAGTC
F T G S G S G T D F T L T I S S

     260     270     280     290     300
TGCAGGCTGAAGACGTGGCAGTTTATTACTGTCAGAATGATTATAGTTAT
L Q A E D V A V Y Y C Q N D Y S Y
                      CDR3

     310     320     330
CCTCTCACGTTCGGTCAGGGGACCAAGCTGGAGATCAAA (SEQ ID NO:72)
P L T F G Q G T K L E I K (SEQ ID NO:48)
```

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(Figure 7B) Light chain VK2

```

      10      20      30      40      50
GACATTGTGATGACACAGTCTCCAGCCTCCCTGTCTGTGACACCAGGAGA
D I V M T Q S P A S L S V T P G E

      60      70      80      90     100
GAAGGTCACTATCACCTGCAAGTCCAGTCAGAGTCTGTTAAACAGTGGAA
K V T I T C K S S Q S L L N S G
                      CDR1

     110     120     130     140     150
ATCAAAAGAACTACTTGACCTGGTACCAGCAGAAACCAGGGCAGCCTCCT
N Q K N Y L T W Y Q Q K P G Q P P

     160     170     180     190     200
AAACTGTTGATCTACTGGGCATCCACTAGGGAATCTGGGGTCCCTGATCG
K L L I Y W A S T R E S G V P D R
                      CDR2

     210     220     230     240     250
CTTCACAGGCAGTGGATCTGGAACAGATTTCACTCTCACCATCAGCAGTC
F T G S G S G T D F T L T I S S

     260     270     280     290     300
TGCAGGCTGAAGACGTGGCAGTTTATTACTGTCAGAATGATTATAGTTAT
L Q A E D V A V Y Y C Q N D Y S Y
                              CDR3

     310     320     330
CCTCTCACGTTTCGGTCAGGGGACCAAGCTGGAGATCAAA (SEQ ID NO:73)
P L T F G Q G T K L E I K (SEQ ID NO:49)
```

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(Figure 7C) Light chain VK3

10 20 30 40 50
GACATTGTGATGACACAGTCTCCAGCCTTCCTGTCTGTGACACCAGGAGA
D I V M T Q S P A F L S V T P G E

60 70 80 90 100
GAAGGTCACCTATCACCTGCAAGTCCAGTCAGAGTCTGTTAAACAGTGGAA
K V T I T C K S S Q S L L N S G
CDR1

110 120 130 140 150
ATCAAAAGAACTACTTGACCTGGTACCAGCAGAAACCAGGGCAGCCTCCT
N Q K N Y L T W Y Q Q K P G Q P P

160 170 180 190 200
AAACTGTTGATCTACTGGGCATCCACTAGGGAATCTGGGGTCCCTGATCG
K L L I Y W A S T R E S G V P D R
CDR2

210 220 230 240 250
CTTCACAGGCAGTGGATCTGGAACAGATTTCACTCTCACCATCAGCAGTC
F T G S G S G T D F T L T I S S

260 270 280 290 300
TGCAGGCTGAAGACGTGGCAGTTTATTACTGTCAGAATGATTATAGTTAT
L Q A E D V A V Y Y C Q N D Y S Y
CDR3

310 320 330
CCTCTCACGTTCGGTCAGGGGACCAAGCTGGAGATCAAA (SEQ ID NO:74)
P L T F G Q G T K L E I K (SEQ ID NO:50)

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(Figure 7D) Light chain VK4

```

      10      20      30      40      50
GACATTGTGATGACACAGTCTCCAGCCTTCCTGTCTGTGACACCAGGAGA
D I V M T Q S P A F L S V T P G E

      60      70      80      90     100
GAAGGTCACCTATCACCTGCAAGTCCAGTCAGAGTCTGTTAAACAGTGGAA
K V T I T C K S S Q S L L N S G
                      CDR1

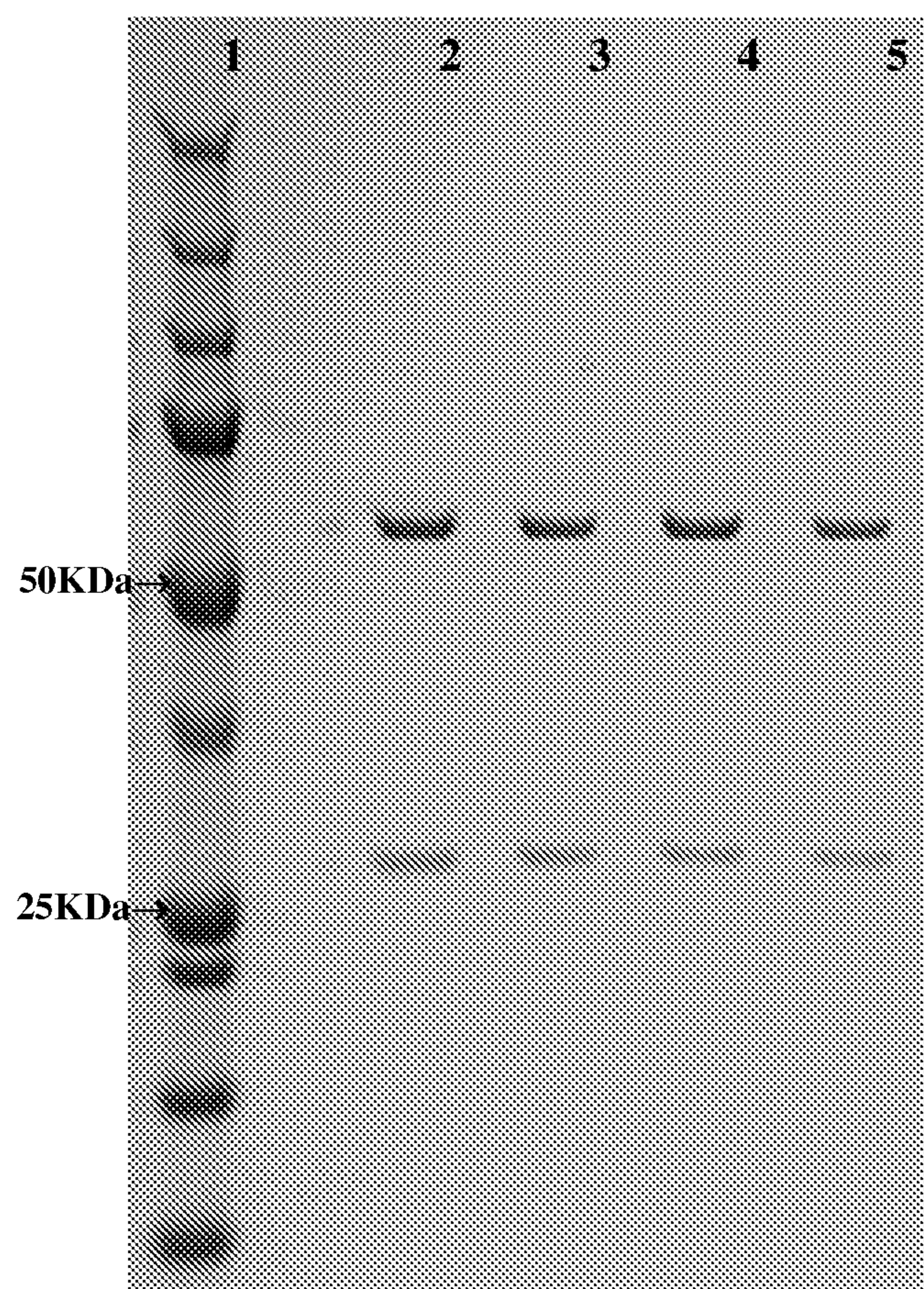
     110     120     130     140     150
ATCAAAAGAACTACTTGACCTGGTACCAGCAGAAACCAGGGCAGCCTCCT
N Q K N Y L T W Y Q Q K P G Q P P

     160     170     180     190     200
AAACTGTTGATCTACTGGGCATCCACTAGGGAATCTGGGGTCCCTGATCG
K L L I Y W A S T R E S G V P D R
                      CDR2

     210     220     230     240     250
CTTCTCCGGCAGTGGATCTGGAACAGATTTCACTCTCACCATCAGCAGTC
F S G S G S G T D F T L T I S S

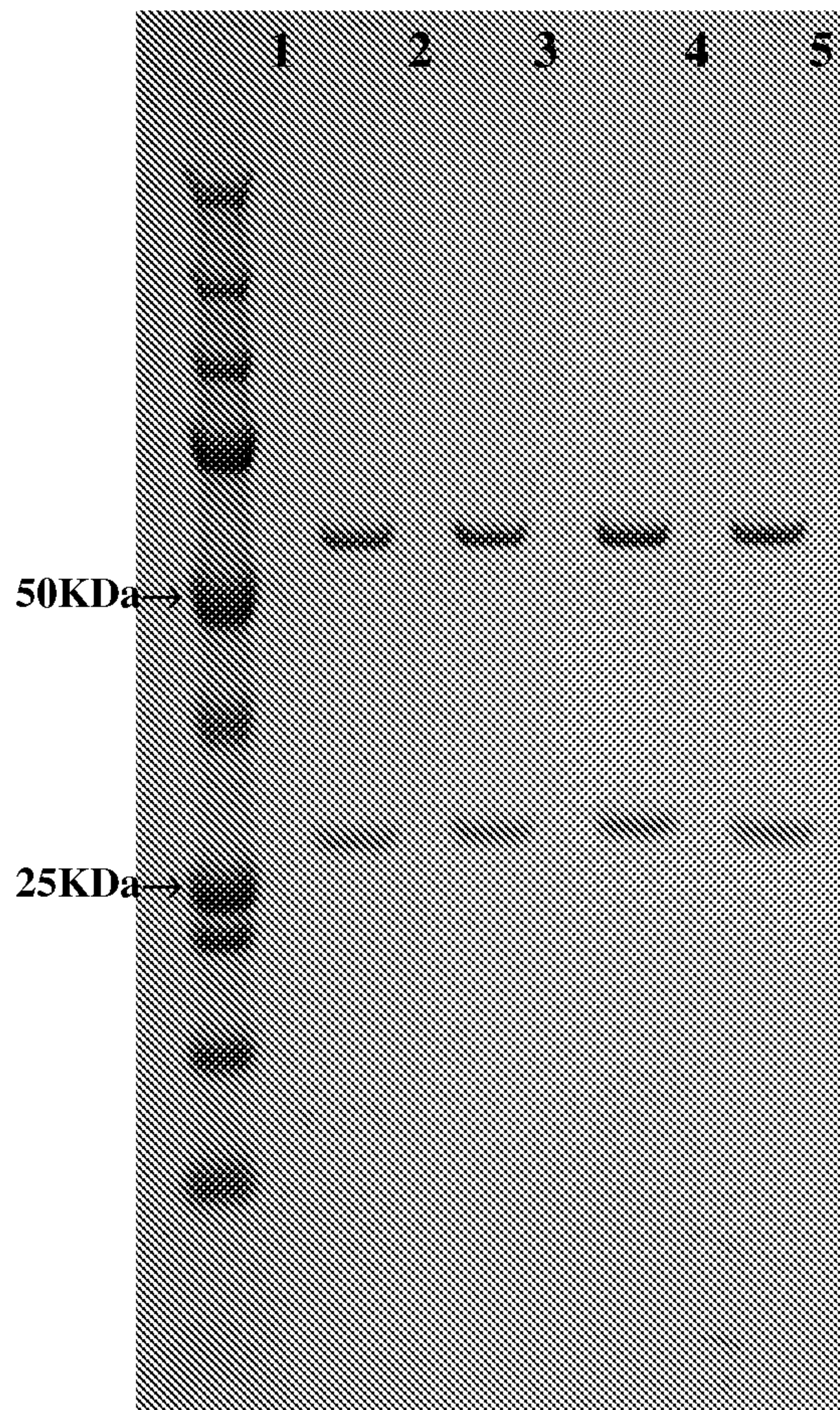
     260     270     280     290     300
TGCAGGCTGAAGACGTGGCAGTTTATTACTGTCAGAATGATTATAGTTAT
L Q A E D V A V Y Y C Q N D Y S Y
                      CDR3

     310     320     330
CCTCTCACGTTCGGTCAGGGGACCAAGCTGGAGATCAAA (SEQ ID NO:75)
P L T F G Q G T K L E I K (SEQ ID NO:51)
```

Figure 8. Purification of EH12.2H7 Composite, human Antibodies**(Figure 8A) Coomassie Blue Stained SDS-PAGE of Purified EH12.2H7 Antibodies:**

Lane 1: Bio-Rad Precision Marker

Lane 2: VH4/V κ 4Lane 3: VH4/V κ 3Lane 4: VH3/V κ 4Lane 5: VH3/V κ 31 μ g of each antibody was loaded

(Figure 8B) Coomassie Blue Stained SDS-PAGE of Purified 29E.2A3 Antibodies:

Lane 1: Bio-Rad Precision Marker

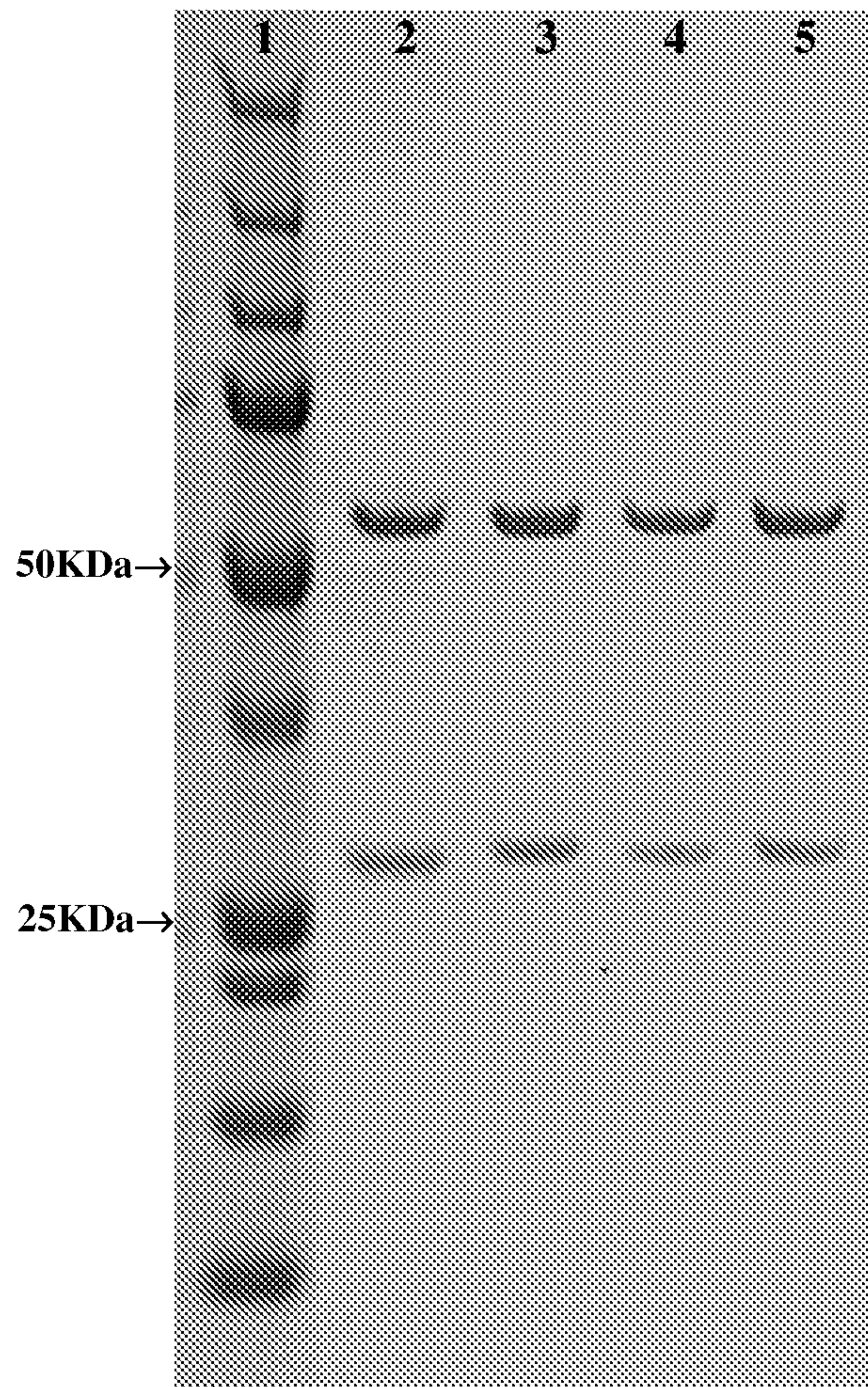
Lane 2: VH4/V κ 2

Lane 3: VH2/V κ 4

Lane 4: VH2/V κ 1

Lane 5: VH2/V κ 2

1 μ g of each antibody was loaded

(Figure 8C) Coomassie Blue Stained SDS-PAGE of Purified 24F.10C12 Antibodies:

Lane 1: Bio-Rad Precision Marker

Lane 2: VH4/V κ 4

Lane 3: VH4/V κ 2

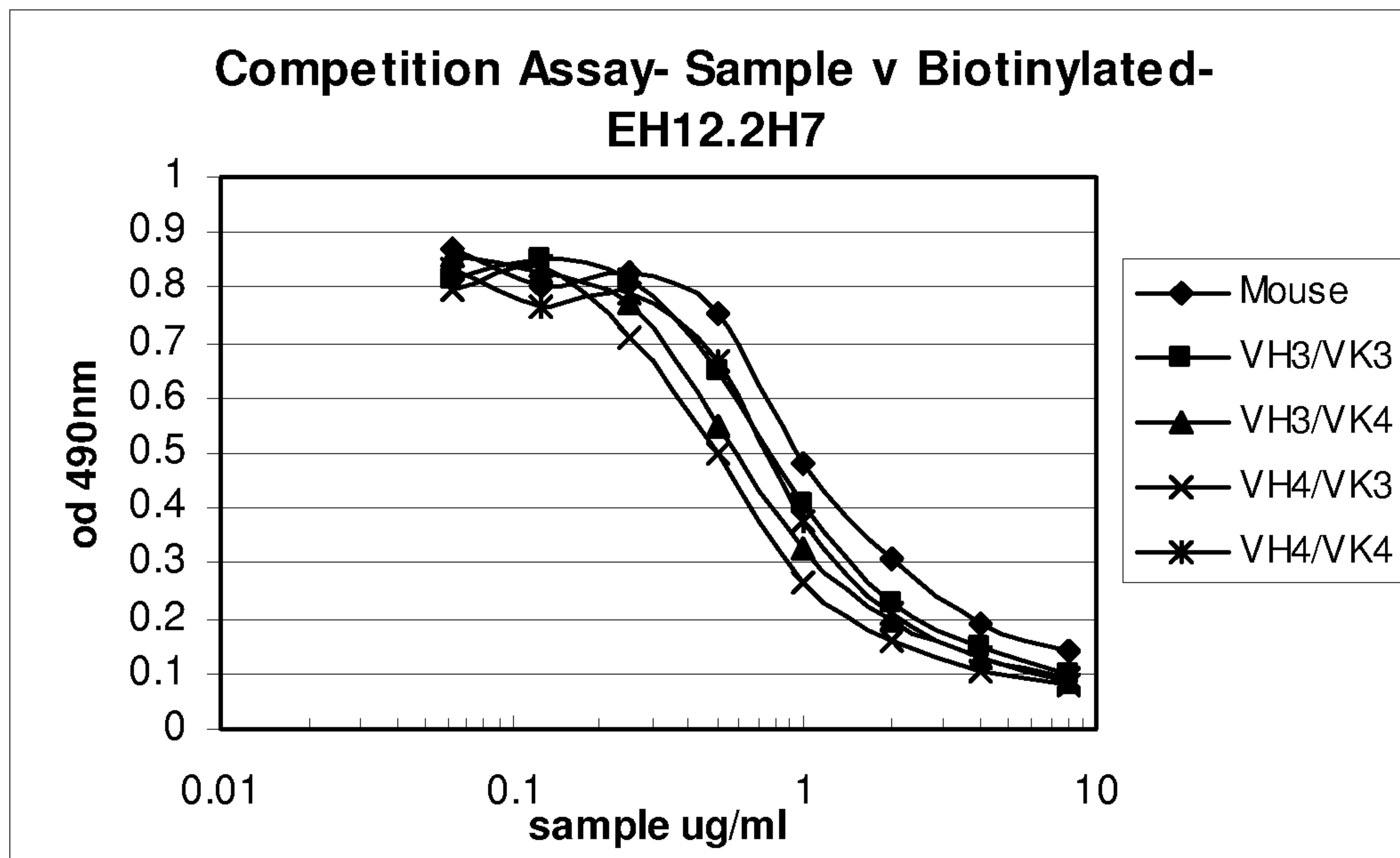
Lane 4: VH2/V κ 3

Lane 5: VH2/V κ 2

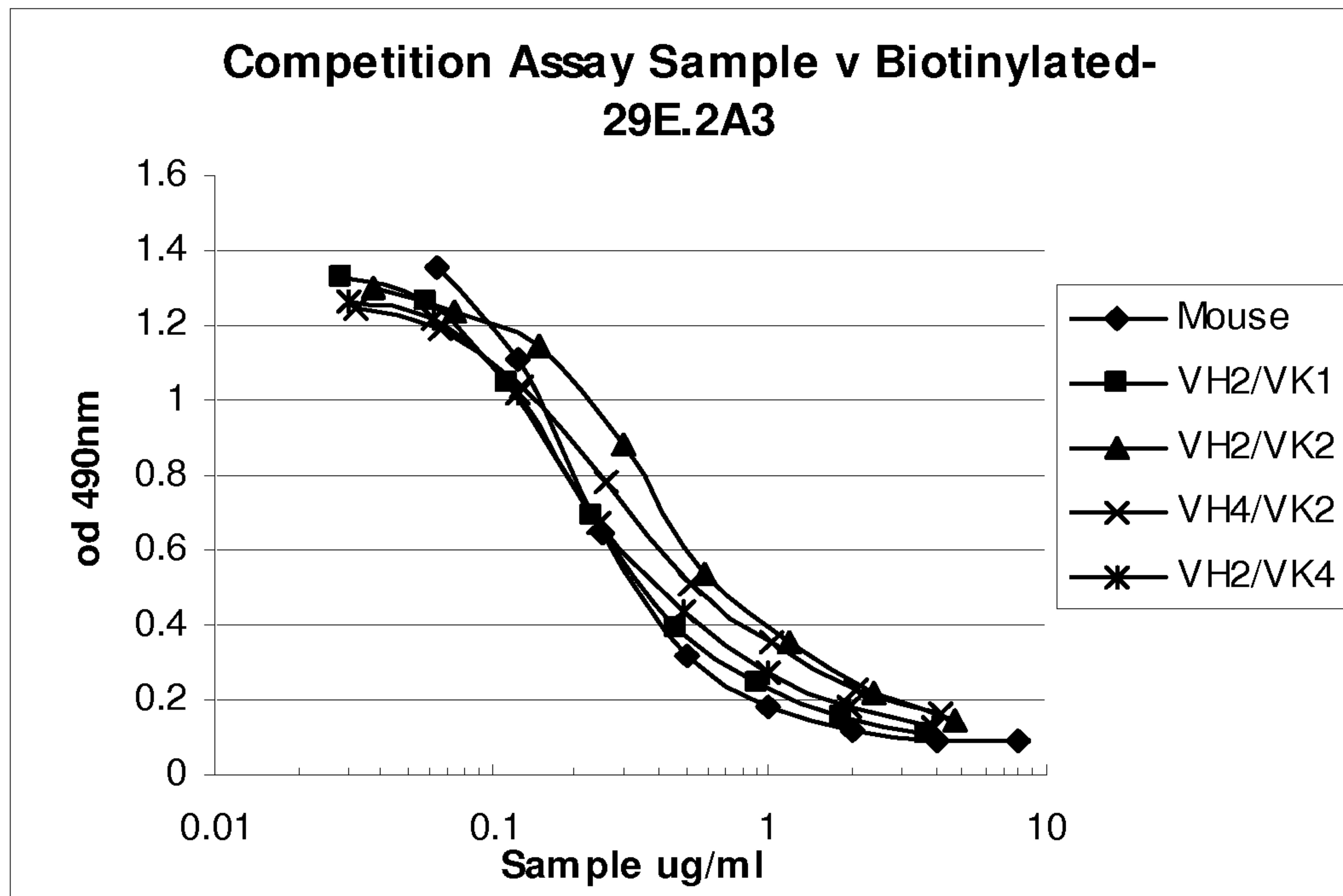
1 μ g of each antibody was loaded

Figure 9. Comparison of Composite, human Antibodies Activities to Mouse Reference Antibody

(Figure 9A) Human PD-1 Competition ELISA:



(Figure 9B) Human PD-L1 Competition ELISA:



(Figure 9C) Human PD-L2 Competition ELISA:

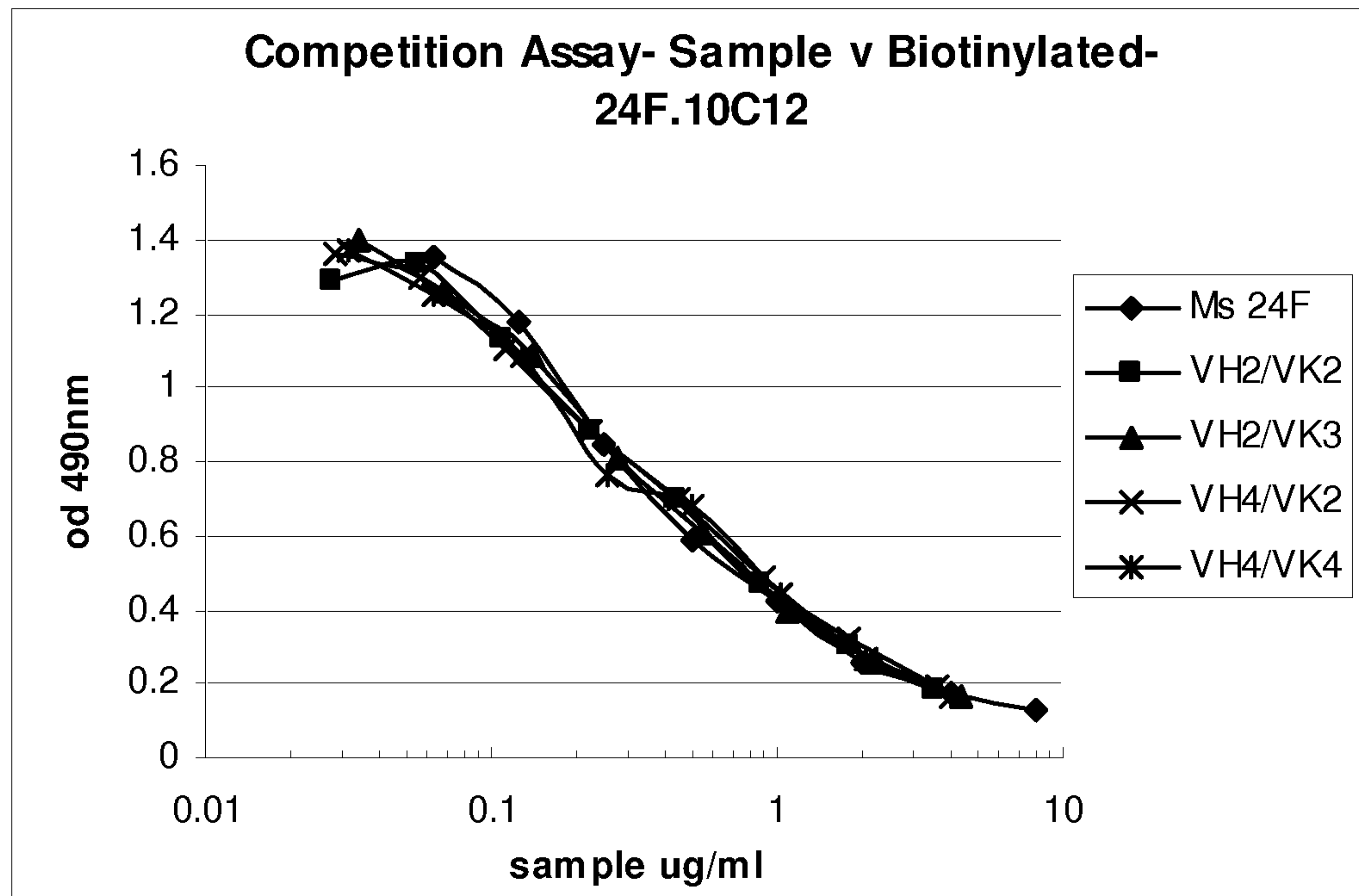


Figure 10: IC₅₀ Binding Comparing Mouse anti-Human Antibodies with Composite, Human Antibodies**(Figure 10A) Competition with EH12.2H7 for binding to PD-1**

	VH1	VH2	VH3	VH4	VH5
VK1	0.82	0.78	0.82	0.77	ND
VK2	0.66	0.98	0.82	0.98	ND
VK3	0.82	0.98	0.76	0.46	ND
VK4	ND	0.90	0.60	0.74	ND

(Figure 10B) Competition with 20E.283 for binding to PD-L1

	VH1	VH2	VH3	VH4	VH5
VK1	3.61	0.96	3.21	2.10	5.96
VK2	3.34	1.75	1.68	3.00	7.8
VK3	2.26	2.26	1.92	3.16	9.16
VK4	5.10	1.04	1.64	2.96	7.04

(Figure 10C) Competition with 24F.10C12 for binding to PD-L2

	VH1	VH2	VH3	VH4	VH5
VK1	0.82	0.78	0.82	0.77	ND
VK2	0.66	0.98	0.82	0.98	ND
VK3	0.82	0.98	0.76	0.46	ND
VK4	ND	0.90	0.60	0.74	ND

Figure 11: Amino Acid Sequences for PD-1, PD-L1 and PD-L2**PD-1 amino acid sequence (SEQ ID NO: 2)**

```
MQIPQAPWPV VWAVLQLGWR PGWFLDSPDR PWNPPTFSPA LLVVTEGDNA 50
TFTCSFSNTS ESFVLNWYRM SPSNQTDKLA AFPEDRSQPG QDCRFRVTQL 100
PNGRDFHMSV VRARRNDSGT YLCGAISLAP KAQIKESLRA ELRVTERRAE 150
VPTAHPSPSP RPAGQFQTLV VGVVGGLLGS LVLLVWVLAV ICSRAARGTI 200
GARRTGQPLK EDPSAVPVFS VDYGELDFQW REKTPEPPVP CVPEQTEYAT 250
IVFPSGMGTS SPARRGSADG PRSAQPLRPE DGHCSWPL 288
```

PD-L1 amino acid sequence (SEQ ID NO: 4)

```
MRIFAVFIFM TYWHLLNAFT VTVPKDLYVV EYGSNMTIEC KFPVEKQLDL 50
AALIVYWEME DKNIIQFVHG EEDLKVQHSS YRQRARLLKD QLSLGNAALQ 100
ITDVKLQDAG VYRCMISYGG ADYKRITVKV NAPYNKINQR ILVVDPTSE 150
HELTCAEGY PKAEVIWTSS DHQVLSGKTT TTNSKREEKL FNVSTSLRIN 200
TTTNEIFYCT FRRLDPEENH TAEVPIPELP LAHPPNERTH LVILGAILLC 250
LGVALTFIFR LRKGRMMDVK KCGIQDTNSK KQSDTHLEET 290
```

PD-L2 amino acid sequence (SEQ ID NO: 6)

```
MIFLLLMLSL ELQLHQIAAL FTVTVPKELY IIEHGSNVTL ECNFDTGSHV 50
NLGAITASLQ KVENDTSPHR ERATLLEEQL PLGKASFHIP QVQVRDEGQY 100
QCIIIIYGVAV DYKYLTLKVK ASYRKINTHI LKVPETDEVE LTCQATGYPL 150
AEVSWPNVSV PANTSHSRTP EGLYQVTSVL RLKPPPGRNF SCVFWNTHVR 200
ELTLASIDLQ SQMEPRTHPT WLLHIFIPFC IIAFIFIATV IALRKQLCQK 250
LYSSKDTTKR PVTTTKREVN SAI 273
```

Figure 12: CDR Amino Acid Sequences for Composite, Human Antibodies

Antibody	Chain	CDR	Sequence	SEQ ID NO.
Anti-PD-1	Heavy	CDR1	SSWIH	7
		CDR2	YIYPSTGFTEYNQKFKD	8
		CDR3	WRDSSGYHAMDY	9
	Light	CDR1	RASQSVSTSGYSYMH	10
		CDR2	FGSNLES	11
		CDR3	QHSWEIPYT	12
Anti-PD-L1	Heavy	CDR1	SYVMH	13
		CDR2	YVNPFDNGTKYNEMFKG	14
		CDR3	QAWGYP	15
	Light	CDR1	RATESVEYYGTSLVQ	16
		CDR2	AASSVDS	17
		CDR3	QQSRRVPYT	18
Anti-PD-L2	Heavy	CDR1	GYTMH	19
		CDR2	YINPRSGYTEYNQKFKD	20
		CDR3	PWFAY	21
	Light	CDR1	KSSQSLLNSGNQKNYLT	22
		CDR2	WASTRES	23
		CDR3	QNDYSYPLT	24

Figure 13: The amino acid sequences for the heavy and light chains of composite human antibody variable regions.

Anti-PD-1 Heavy Chain VH1 (SEQ ID NO 25)

QVQLVQSGAELKQPGASVKMSCKASGYSFTSSWIHWVKQAPGQGLEWIGYIYPSTGFTEYNQKFKDRA
TLTADKSTSTAYMELSSLRSEDSAVYYCARWRDSSGYHAMDYWGQGTSTVTVSS

Anti-PD-1 Heavy Chain VH2 (SEQ ID NO 26)

QVQLVQSGAEVKQPGASVKMSCKASGYSFTSSWIHWVKQAPGQGLEWIGYIYPSTGFTEYNQKFKDRA
TLTADKSTSTAYMELSSLRSEDTAVYYCARWRDSSGYHAMDYWGQGTSTVTVSS

Anti-PD-1 Heavy Chain VH3 (SEQ ID NO 27)

QVQLVQSGHEVKQPGASVKMSCKASGYSFTSSWIHWVKQAPGQGLEWIGYIYPSTGFTEYNQKFKDRA
TLTADKSTSTAYMELSSLRSEDTAVYYCARWRDSSGYHAMDYWGQGTSLVTVSS

Anti-PD-1 Heavy Chain VH4 (SEQ ID NO 28)

QVQLVQSGHEVKQPGASVKMSCKASGYSFTSSWIHWVRQAPGQGLEWIGYIYPSTGFTEYNQKFKDRA
TLTADKSTSTAYMELSSLRSEDTAVYYCARWRDSSGYHAMDYWGQGTSLVTVSS

Anti-PD-1 Heavy Chain VH5 (SEQ ID NO 29)

QVQLVQSGHEVKQPGASVKVSKASGYSFTSSWIHWVRQAPGQGLEWIGYIYPSTGFTEYNQKFKDRA
TITADKSTSTAYMELSSLRSEDTAVYYCARWRDSSGYHAMDYWGQGTSLVTVSS

Anti-PD-1 Light Chain VK1 (SEQ ID NO 30)

DIVLTQSPASLTLSLSPGQRLTISCRASQSVSTSGYSYMHWYQQKPDQSPKLLIKFGSNLESGIPARFSG
SGSGTDFTLTISSLEEEDFATYYCQHSWEIPYTFGQGGTKLEIK

Anti-PD-1 Light Chain VK2 (SEQ ID NO 31)

DIVLTQSPATLSLSPGQRLTISCRASQSVSTSGYSYMHWYQQKPDQSPKLLIKFGSNLESGIPARFSG
SGSGTDFTLTISSLEPEDFATYYCQHSWEIPYTFGQGGTKLEIK

Anti-PD-1 Light Chain VK3 (SEQ ID NO 32)

EIVLTQSPATLSLSPGQRLTISCRASQSVSTSGYSYMHWYQQKPDQSPKLLIKFGSNLESGIPARFSG
SGSGTDFTLTISSLEPEDFATYYCQHSWEIPYTFGQGGTKLEIK

Anti-PD-1 Light Chain VK4 (SEQ ID NO 33)

DIVLTQSPATLSLSPGQRLTISCRASQSVSTSGYSYMHWYQQKPDQSPKLLIKFGSNLESGIPARFSG
SGSGTDFTLTISSLEPEDFAVYYCQHSWEIPYTFGQGGTKLEIK

Anti-PD-L1 Heavy Chain VH1 (SEQ ID NO 34)

EVQLVQSGPELKKPGASVKMSCKASGYTFTSYVMHWVKQAPGQRLEWIGYVNPFDGTYNEMFKGRA
TLTSDKSTSTAYMELSSLRSEDSAVYYCARQAWGYPWGQGTSLVTVSS

Anti-PD-L1 Heavy Chain VH2 (SEQ ID NO 35)

EVQLVQSGAEVKKPGASVKMSCKASGYTFTSYVMHWVKQAPGQRLEWIGYVNPFDGTYNEMFKGRA
TLTSDKSTSTAYMELSSLRSEDTAVYYCARQAWGYPWGQGTSLVTVSS

Figure 13 (Continued)**Anti-PD-L1 Heavy Chain VH3 (SEQ ID NO 36)**

EVQLVQSGAEVKKPGASVKMSCKASGYTFTSYVMHWVRQAPGQRLEWIGYVNP FNDGTKYNEMFKGRA
TLTSDKSTSTAYMELSSLRSED TAVYYCARQAWGYPWGQGTLVTVSS

Anti-PD-L1 Heavy Chain VH4 (SEQ ID NO 37)

EVQLVQSGAEVKKPGASVKV SCKASGYTFTSYVMHWVRQAPGQRLEWIGYVNP FNDGTKYNEMFKGRA
TLTSDKSTSTAYMELSSLRSED TAVYYCARQAWGYPWGQGTLVTVSS

Anti-PD-L1 Heavy Chain VH5 (SEQ ID NO 38)

EVQLVQSGAEVKKPGASVKV SCKASGYTFTSYVMHWVRQAPGQRLEWIGYVNP FNDGTKYNEMFKGRA
TITSDKSTSTAYMELSSLRSED TAVYYCARQAWGYPWGQGTLVTVSS

Anti-PD-L1 Light Chain VK1 (SEQ ID NO 39)

DIVLTQSPASLALSPGERATLSCRATESVEYYG TSLVQWYQQKPGQP PKLLIYAASSVDSGVPSRFSG
SGSGTDFTLTINSLEEEDAAMYFCQQSRRVPYTFGQG TKLEIK

Anti-PD-L1 Light Chain VK2 (SEQ ID NO 40)

DIVLTQSPATLSLSPGERATLSCRATESVEYYG TSLVQWYQQKPGQP PKLLIYAASSVDSGVPSRFSG
SGSGTDFTLTINSLEAEDAAMYFCQQSRRVPYTFGQG TKLEIK

Anti-PD-L1 Light Chain VK3 (SEQ ID NO 41)

EIVLTQSPATLSLSPGERATLSCRATESVEYYG TSLVQWYQQKPGQP PKLLIYAASSVDSGVPSRFSG
SGSGTDFTLTINSLEAEDAAMYFCQQSRRVPYTFGQG TKLEIK

Anti-PD-L1 Light Chain VK4 (SEQ ID NO 42)

DIVLTQSPATLSLSPGERATLSCRATESVEYYG TSLVQWYQQKPGQP PKLLIYAASSVDSGVPSRFSG
SGSGTDFTLTINSLEAEDAATYFCQQSRRVPYTFGQG TKLEIK

Anti-PD-L2 Heavy Chain VH1 (SEQ ID NO 43)

QVQLVQSGAELKKPGASVKMSCKASGYTFTGYTMHWVKQAPGQGLEWIGYINPRSGYTEYNQKFKDRT
TLTADKSTSTAYMELSSLRSEDSAVYYCARPWFAYWGQGTLVTVSS

Anti-PD-L2 Heavy Chain VH2 (SEQ ID NO 44)

QVQLVQSGAEVKKPGASVKMSCKASGYTFTGYTMHWVKQAPGQGLEWIGYINPRSGYTEYNQKFKDRT
TLTADKSTSTAYMELSSLRSED TAVYYCARPWFAYWGQGTLVTVSS

Anti-PD-L2 Heavy Chain VH3 (SEQ ID NO 45)

QVQLVQSGAEVKKPGASVKMSCKASGYTFTGYTMHWVRQAPGQGLEWIGYINPRSGYTEYNQKFKDRT
TLTADKSTSTAYMELSSLRSED TAVYYCARPWFAYWGQGTLVTVSS

Anti-PD-L2 Heavy Chain VH4 (SEQ ID NO 46)

QVQLVQSGAEVKKPGASVKV SCKASGYTFTGYTMHWVRQAPGQGLEWIGYINPRSGYTEYNQKFKDRT
TLTADKSTSTAYMELSSLRSED TAVYYCARPWFAYWGQGTLVTVSS

Figure 13 (Continued)**Anti-PD-L2 Heavy Chain VH5 (SEQ ID NO 47)**

QVQLVQSGAEVKKPGASVKVSCKASGYTFTGYTMHWVRQAPGQGLEWIGYINPRSGYTEYNQKFKDRT
TITADKSTSTAYMELSSLRSEDVAVYYCARPWFAYWGQGTLLVTVSS

Anti-PD-L2 Light Chain VK1 (SEQ ID NO 48)

DIVMTQSPASLTVPGEKVTITCKSSQSLLNSGNQKNYLTWYQQKPGQPPKLLIWASTRESGVPDRF
TGSGSGTDFTLTISLQAEDVAVYYCQNDYSYPLTFGQGTKLEIK

Anti-PD-L2 Light Chain VK2 (SEQ ID NO 49)

DIVMTQSPASLSVTPGEKVTITCKSSQSLLNSGNQKNYLTWYQQKPGQPPKLLIWASTRESGVPDRF
TGSGSGTDFTLTISLQAEDVAVYYCQNDYSYPLTFGQGTKLEIK

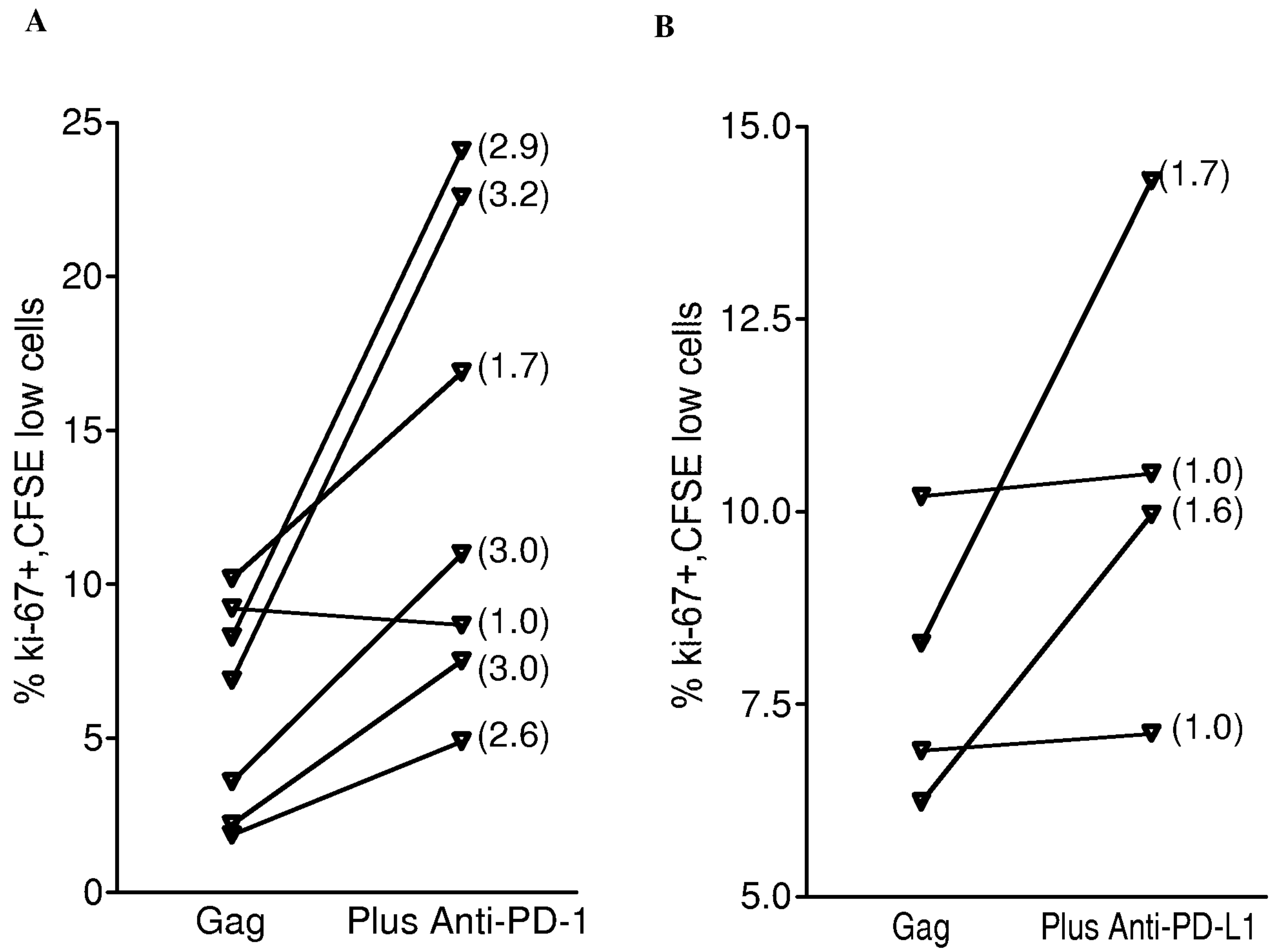
Anti-PD-L2 Light Chain VK3 (SEQ ID NO 50)

DIVMTQSPAFLSVTPGEKVTITCKSSQSLLNSGNQKNYLTWYQQKPGQPPKLLIWASTRESGVPDRF
TGSGSGTDFTLTISLQAEDVAVYYCQNDYSYPLTFGQGTKLEIK

Anti-PD-L2 Light Chain VK4 (SEQ ID NO 51)

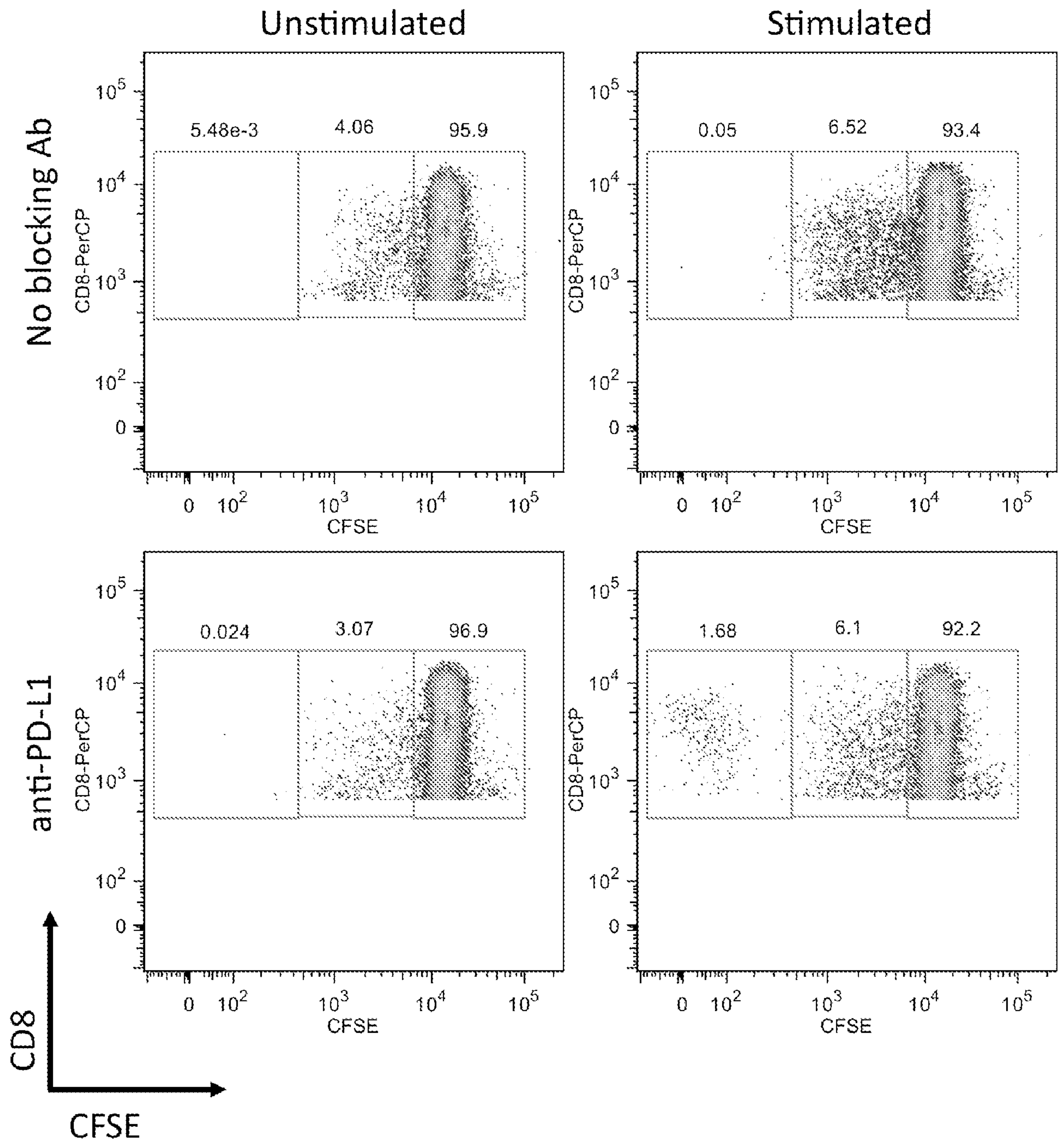
DIVMTQSPAFLSVTPGEKVTITCKSSQSLLNSGNQKNYLTWYQQKPGQPPKLLIWASTRESGVPDRF
SGSGSGTDFTLTISLQAEDVAVYYCQNDYSYPLTFGQGTKLEIK

Figure 14



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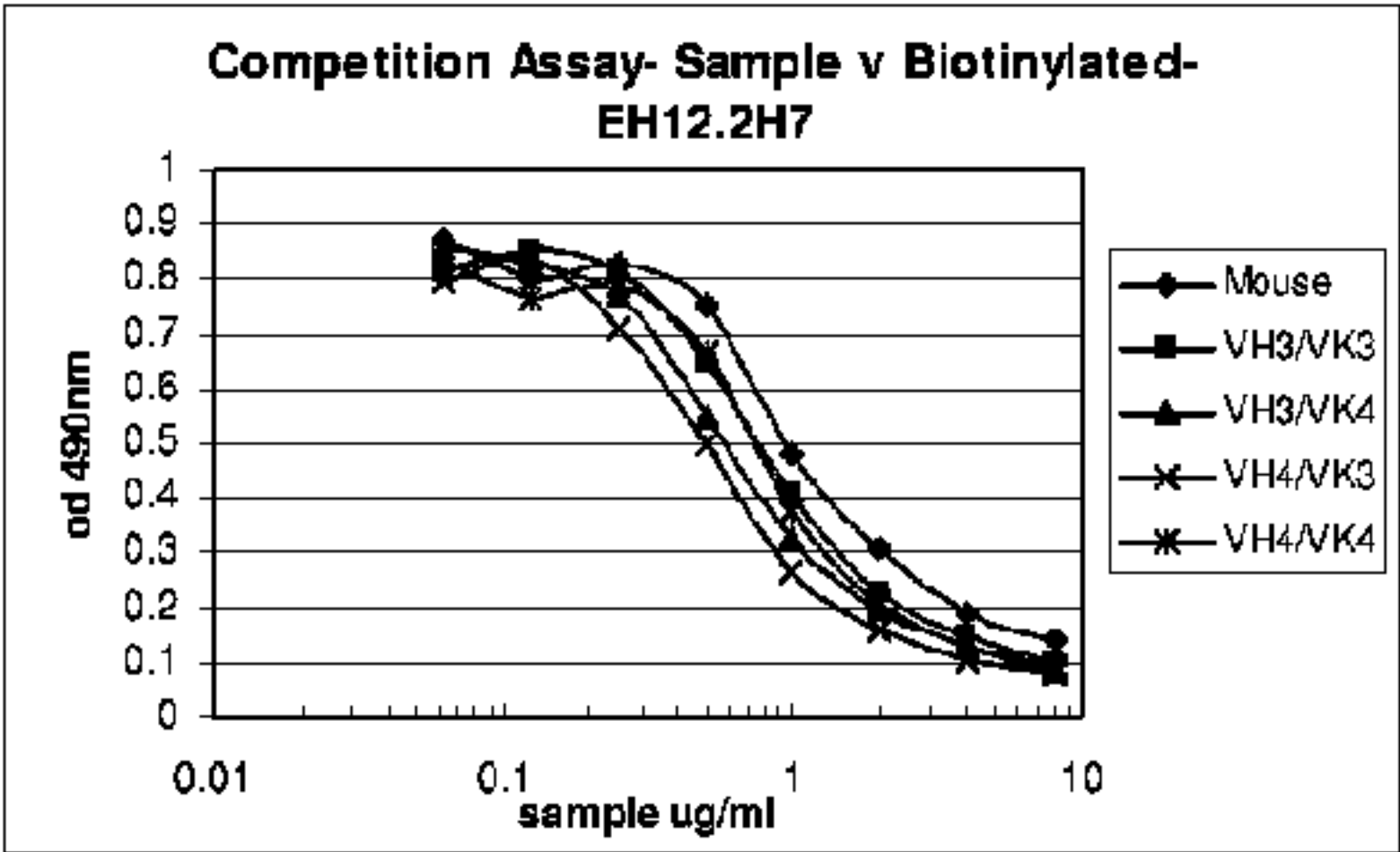
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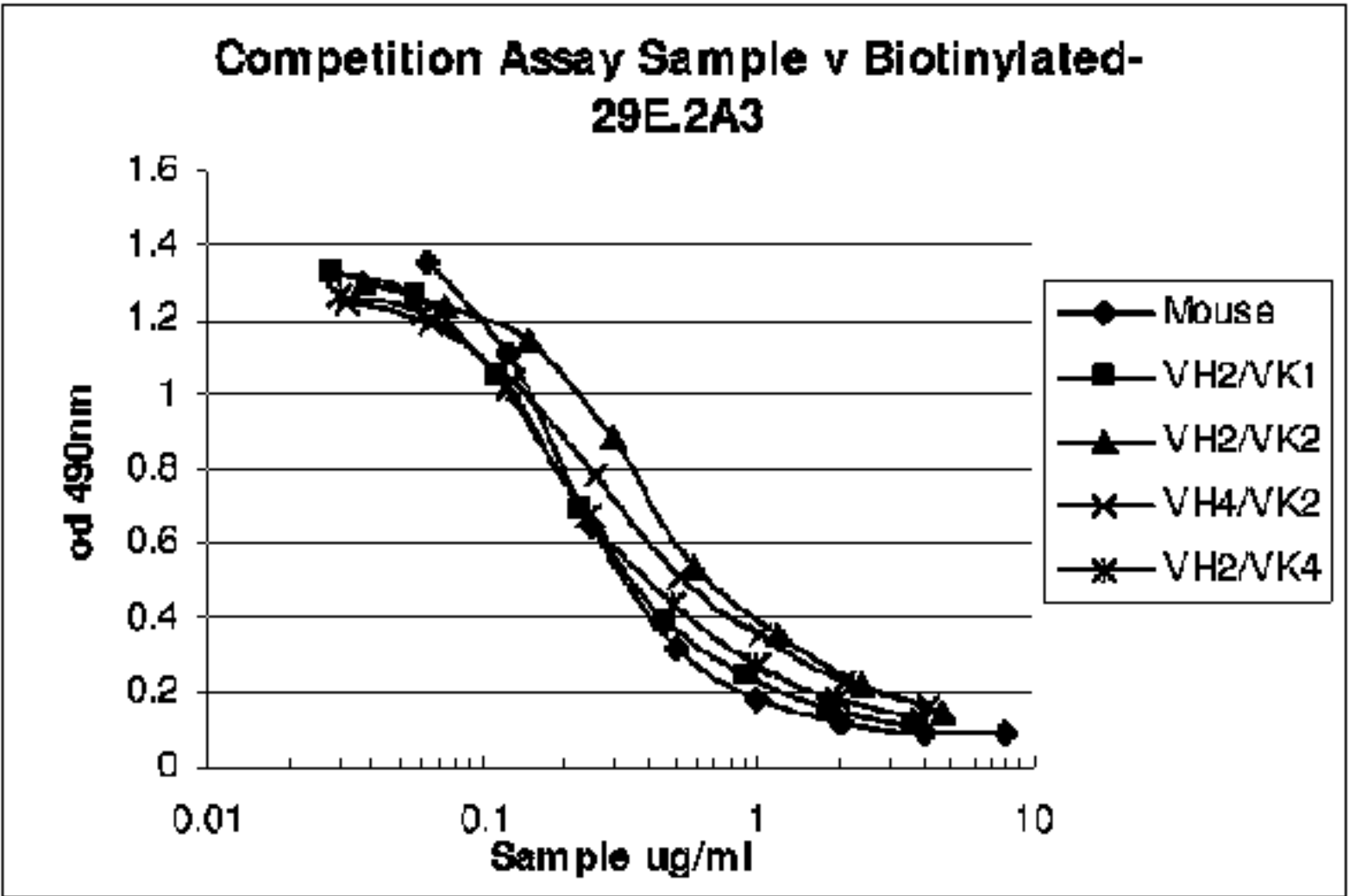
Comparison of Composite, human Antibodies Activities to Mouse Reference

Antibody

(A) Human PD-1 Competition ELISA:



(B) Human PD-L1 Competition ELISA:



(C) Human PD-L2 Competition ELISA:

