Feb. 4, 1969 P. E. GLASER ET AL 3,425,060

PROTECTIVE GARMENT

Filed Jan. 25, 1965

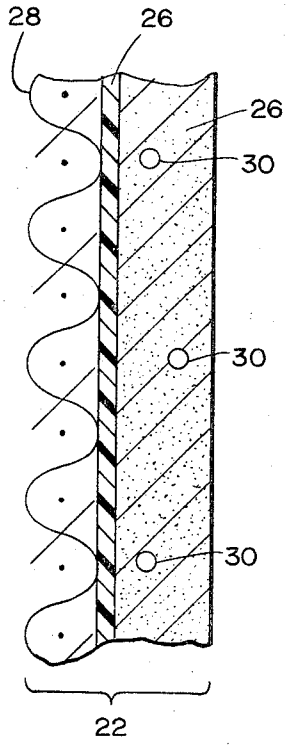

FIG. 3

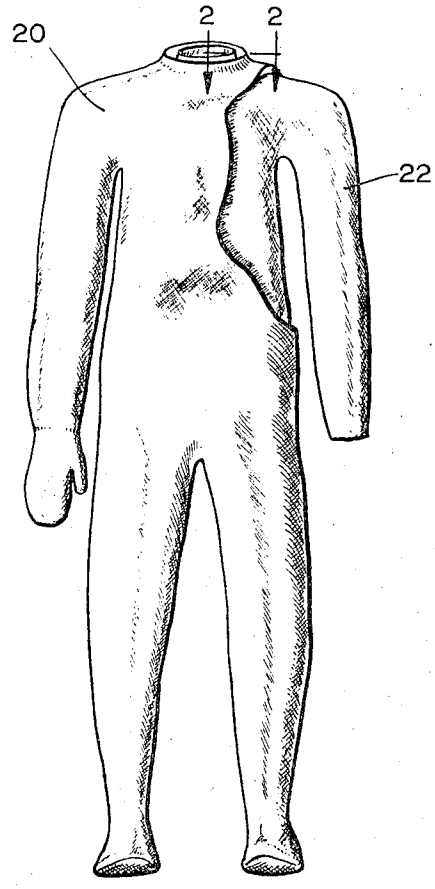

FIG. 1

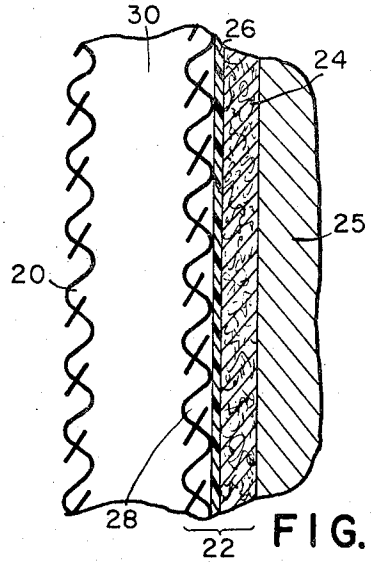

FIG. 2

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PROTECTIVE GARMENT

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ABSTRACT OF THE DISCLOSURE

A space suit including an outer air-impermeable sheath and an inner garment of multiply fabric, the fabric comprising an inner ply of flexible, moisture-absorbent material, an outer ply of flexible, elastic, porous material, and sandwiched between the inner and outer plys, a continuous, flexible, moisture-permeable material. The inner ply may also include a network of conduits through which cooling fluid can be passed.

This invention relates to protective garments and more particularly to a garment particularly adapted for use in a substantially vacuum environment.

Known vacuum or space suits generally fall into one of two categories, "soft" or flexible suits, and "hard" suits. "Soft" suits generally comprise an externally worn, vapor impermeable, flexible covering which also usually provides thermal insulation, and are typically internally pressurized to about 5 p.s.i. Suits of this type have a number of drawbacks. When pressurized, the suit tends to restrict arm and leg movement due to the tendency of the suit to balloon and form cylindrical enclosures about the wearer's extremities. To confer flexibility on the suit, the covering is usually quite thin and its inherent susceptibility to puncture or ripping can lead to catastrophic pressure loss from inside the suit. Upon explosive decompression, which abruptly reduces external pressure on the body, hemorrhagic rupture of the lung is expected. Additionally, flash dehydration of the skin will tend to occur.

The "hard" suit comprises a number of rigid, body enclosing portions coupled at the joints through flexible bellows. In suits of this latter type, the danger of puncture is reduced, but leakage at the flexible joints is a possibility. Additionally, although "hard" suits offer superior protection, they are of sharply limited utility in that they greatly restrict freedom of movement.

It is, therefore, a principal object of the present invention to provide a garment which confers a degree of mobility, similar to that of the aforementioned "soft" suit, upon the wearer, yet provides protection from the immediate consequences of puncture or ripping. Yet another object of the present invention is to provide means for increasing the reliability of known space garments.

Other objects of the invention will in part be obvious and will in part appear hereinafter. The invention accordingly comprises the product possessing the features, properties and relation of components which are exemplified in the following detailed disclosure, and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the present invention, reference should be had to the following detailed description taken in connection with the accompanying drawing wherein FIG. 1 is a front view partly cut away showing a space suit embodying the principals of the present invention and including inner and outer garments; FIG. 2 shows section taken along the

line 2—2 of FIG. 1, showing the relation of the outer and inner garments to the skin of the wearer; and FIG. 3 is a schematic cross section similar to FIG. 2 showing an alternative embodiment of the fabric of the inner garment.

The foregoing objects are generally effected by providing a garment including enclosure means, spaced some distance from the skin, for withstanding the pressure of air held in the space between the enclosure means and the skin, for providing thermal insulation, and for controlling radiation interchange with the surrounding environment. Such an enclosure means can be of conventional type. In order to provide the desired reliability and additional protection, additional means are also included for enclosing the wearer's body with a protective barrier in intimate, substantially continuous contact with the body. This barrier exerts a substantially continuous, uniform, mechanical pressure inwardly upon the skin of the wearer whilst permitting the controlled transfer of water vapor from the latter.

The term "gas" as used herein is to be understood to include generally water vapor, gases and the like.

Referring now to the drawing there is shown in FIG. 1, a space suit comprising an outer garment **20** and an inner sheath **22**. FIG. 2 shows a fragment of outer garment **20**. The latter typically is a fabric or membrane that is gas impermeable, strong enough to withstand reasonable pressure differential between gas and vacuum on opposite sides thereof (e.g. 5 p.s.i.) without rupture or leakage, is fairly tear and puncture resistant, and has an external surface which has been treated as by painting, so as to provide a desired degree of radiation interchange between the surface and the surroundings (i.e. space environment). Such fabrics typically are found in known garments presently adapted for use in low-pressure or vacuum environments. The outer garment is preferably in the form adapted to provide a continuous enclosure about the arms, legs and torso of the wearer and includes usual means (not shown) whereby it is connected through a sealed coupling to a helmet.

The invention also comprises an inner sheath **22**, adapted to be entirely enclosed within garment **20**, and which itself is shaped to enclose the arms, legs, and torso of the wearer. Sheath **22** is formed from a multilayer sheet material preferably including inner ply **24** adapted to be positioned adjacent the skin **25** of the wearer, intermediate ply **26** and an outer layer or ply **28**, all as an integral sandwich.

Inner ply **24** is formed of a flexible moisture absorbent sheet material which may be of randomly arranged fibers as a cotton felt, may be of ordered fibrous yarns such as a knitted cotton birdseye fabric or cotton tricot, or the like, or may be non-fibrous, spongy material such as a foamed polymer, e.g. polyurethane. Inner ply **24** is intended to keep surface moisture on the skin below a level at which the fluid would cause discomfort. To further reduce the possibiilty of skin irritation the inner ply can be pretreated to include appropriate soothing medication or emollients. Additionally the inner ply can be provided with cooling fluid passages of thin plastic flexible tubing to permit control of the skin temperature by external apparatus.

Intermediate ply **26** is in the form of a thin flexible membrane permeable to water-vapor for controlling the rate of water-vapor transport between the relatively high concentration of water-vapor expected at inner ply **24** and the relatively lower concentrations of water-vapor expected at outer ply **28**. Sheet materials suitable for use as ply **26** are any of a number of high-molecular weight, synthetic polymers including, for example, polyamines,

polymethyl methacrylate, cellulose acetate, cellulose proprionate, and the like.

Outer ply **28** is a flexible sheet material of high porosity so as to provide substantially no barrier to water-vapor transport, and is preferably elastic within, however, small limits as will be explained hereinafter. In one embodiment of the present invention, ply **28** is a sheet material or fabric formed, as by knitting or weaving, of yarn capable of controlled shrinking. For example, a yarn of irradiated polyethylene shrinks about 50% when heated to a temperature of 100° F. The elasticity of ply **28** can be controlled by incorporating into its structure substantially inelastic material such as metallic fiber or yarn to define the limits of the desired extension.

It will be seen that sheath **22** is intended to contribute to increase mobility of the wearer with respect to conventional "soft" suits, and also considerably increases the reliability of the garment of the invention according to the following:

The sheath is intended to exert a substantially uniform pressure on the skin of the wearer whilst allowing the skin to "breathe." To this end, it is intended that sheath **22** be tailored to fit initially loosely about the desired body portions of the wearer. After being so fitted it is shrunk, as by the application of heat, to outer ply **28** until the inner ply is in substantially continuous contact with the skin at a pressure which counterbalances the internal body pressures. It is understood that because in embodiments where plies **24** and **26** are substantially inelastic, there will be some negligible folding thereof after shrinkage of the outer ply. For this reason it is preferred that plies **24** and **26** have some elasticity and, in the initial structure of sheath **22**, be coupled in a stretched condition to the unshrunk outer ply. It will also be appreciated that were the outer ply to be quite inelastic after shrinkage, normal changes in body volume such as are required for breathing, would be difficult. To this end, it is desirable that ply **28** have sufficient elastic properties (as are found for example in fabric of polypropylene fiber) to allow for such movement. Typically, the elasticity can be limited to a maximum 10% elongation which can be insured by incorporation of metallic threads or fibers into the structure of ply **28** as mentioned above. Furthermore, around joints the sheath can be arranged to have folds which sliding upon each other permit free movements of the extremities.

The entire sheath, as described, is permeable to water vapor. By judicious selection of material for the membrane of ply **26**, the transfer rate of water vapor through sheath **22** can be controlled. The transfer of vapor is due to the existence of a vapor concentration gradient, and such factors as membrane "porosity" and thickness will determine the magnitude of that gradient. Of course, the gradient is greatest when the vapor pressure adjacent to outer ply **28** drops to its lowest value as would occur upon the advent of vacuum conditions. However, even under high vacuum conditions, ply **26** reduces the water vapor transport rate to a level which allows reasonable time for the wearer to take corrective action. Thus, the sheath, when in shrunken relation to the wearer, forms a protective barrier for prevention of skin damage and defluidization, without unduly restricting movement of the wearer.

It will be apparent that ply **28** serves to space ply **26** from garment **20**, the space between the two being preferably filled with a gas **30**, such as air, at a pressure sufficiently large enough to reduce the water-vapor concentration gradient across the membrane of ply **26** to a desired value and small enough to prevent such ballooning of garment **20** as would be difficult to overcome and restrict the movement of the wearer. The value of pressure selected depends largely upon the characteristics of ply **26** but typically, a pressure of about 0.5 p.s.i. will usually be adequate to provide vapor control while not unduly reducing the mobility of the wearer. When the garments are worn in a vacuum environment, of course, this small pressure also serves as means for spacing the outer garment from ply **28** in the sheath.

A number of modifications of the foregoing can readily be made. For example, a fluid-cooled garment can be incorporated into the assembly as by being placed in the interspace between sheath **28** and outer garment **20**. Alternatively, as shown in FIG. 3 conduits **30** for carrying coolant can be incorporated per se directly into the fabric of, for example, ply **24**. Portions of ply **28** can be endowed with various degrees of freedom according to usage; for example, a portion intended to cover the forearm can be woven and a portion intended to cover a joint such as the elbow can be knitted.

Since these and other changes may be made in the above product without departing from the scope of the invention herein involved, it is intended that all matter contained in the above description or shown in the accompanying drawing shall be interpreted in an illustrative and not in a limiting sense.

What is claimed is:

1. A multiply fabric for a garment formed substantially as a unit for enclosing a major portion of a wearer's body and adapted for use in a substantially vacuum environment, said fabric comprising in combination:

a first ply of flexible, moisture absorbent material;

a second ply of a flexible, elastic, porous material formed of a heat-shrinkable, fibrous synthetic polymer; and

a third ply of a moisture-vapor permeable, substantially continuous synthetic polymeric membrane, sandwiched between said first and second plies.

2. A fabric as defined in claim **1** wherein said polymeric fabric is formed or irradiated polyethylene fibers.

3. A fabric as defined in claim **2** wherein said polymeric fabric is knitted.

4. A fabric as defined in claim **1** wherein said second ply includes substantially inelastic fibers for providing a limit to the elasticity of said second ply.

5. A fabric as defined in claim **1** wherein one of said plies includes a continuous network of conduits embedded therein for carrying a coolant fluid.

6. A garment formed substantially as a unit for enclosing the major portions of a wearer's body and adapted for use in a substantially vacuum environment; and garment comprising, in combination;

a multiply inner sheath including, an inner ply of flexible, moisture absorbent fibrous cloth;

an intermediate ply of a moisture permeable, flexible, substantially continuous, synthetic polymeric membrane adapted to control transfer of said moisture therethrough; and

an outerply of a flexible, elastic, porous material of synthetic polymeric yarns, said inner sheath being dimensioned to fit initially loosely about said portion of a wearer's body and said yarns being controllably heat-shrinkable for bringing said inner ply into substantially uniform contact with and maintain a predetermined pressure upon the wearer's body.

7. A garment formed substantially as a unit for enclosing the major portions of a wearer's body and adapted for use in a substantially vacuum environment; said garment comprising, in combination;

a multiply inner sheath including, an inner ply of flexible, moisture absorbent fibrous materials;

an intermediate ply of a moisture vapor-permeable, flexible, substantially continuous membrane;

an outer ply of a flexible, elastic porous material, said inner sheath being initially dimensioned to fit loosely about said portion of a wearer's body and said outer ply being formed of a material which is controllably shrinkable so as to bring said inner ply into substantially uniform contact with and maintain a predeterminer pressure upon the wearer's body; and

an outer garment formed of a thermally-insulating, substantially vapor-impermeable material spaced from

said inner sheath for defining a gas-filled volume between said inner sheath and outer garment.

8. A garment as defined in claim 7 wherein said outer ply is a heat-shrinkable, fibrous, synthetic polymeric fabric.

9. A garment as defined in claim 7 wherein said outer ply includes substantially inelastic fibers for providing a limit to the elasticity of said second ply.

10. A garment as defined in claim 9 wherein said intermediate ply is a synthetic polymeric membrane.

11. Method of forming a garment adapted for use as an inner unit for a space suit, and comprising the steps of;

constructing a multiply fabric sheath having an inner ply of flexible moisture absorbent material, an intermediate ply of a flexible, substantially continuous membrane permeable to moisture vapor, and an outer ply of flexible, elastic, porous shrinkable cloth, and shaped to fit loosely about the arms, legs, and torso of a wearer; and

shrinking said sheath while on said wearer until the shrunken sheath exerts a substantially uniform pressure inwardly upon said arms, legs, and torso sufficient to counterbalance outward pressures otherwise established by the wearer's body in a vacuum environment.

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