Nov. 15, 1966 J. C. GODFREY 3,284,926

MODEL SET FOR REPRESENTING STRUCTURES OF CHEMICALS

Filed Nov. 14, 1963 3 Sheets-Sheet 2

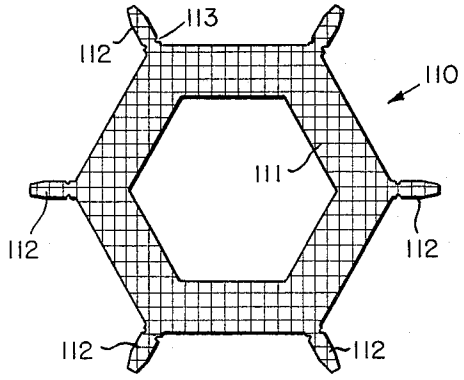


FIG. 10

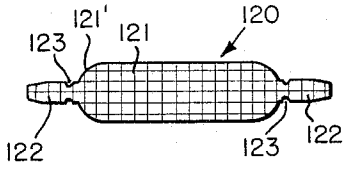


FIG. 11

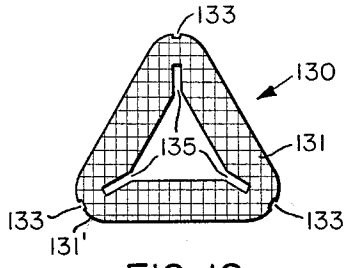


FIG. 12

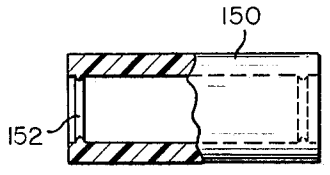


FIG. 13

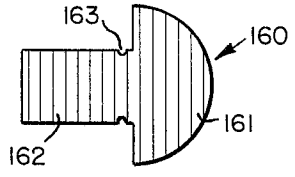


FIG. 14

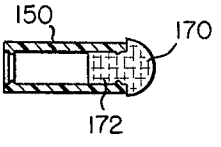


FIG. 15

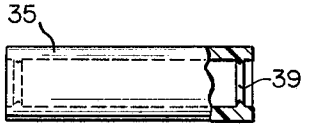


FIG. 17

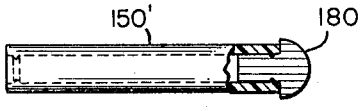


FIG. 16

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MODEL SET FOR REPRESENTING STRUCTURES OF CHEMICALS

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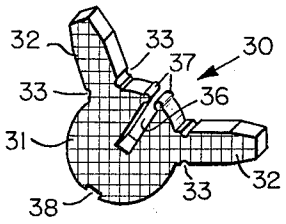


FIG. 1

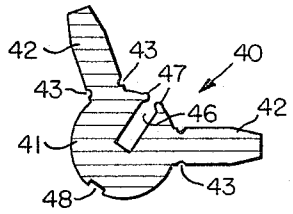


FIG. 2

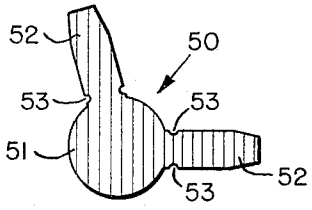


FIG. 3

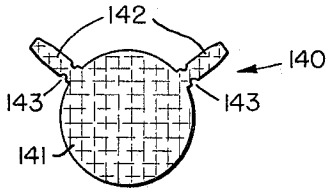


FIG. 4

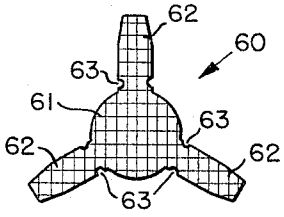


FIG. 5

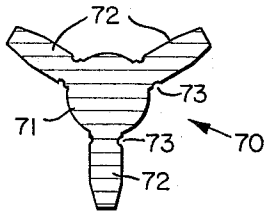


FIG. 6

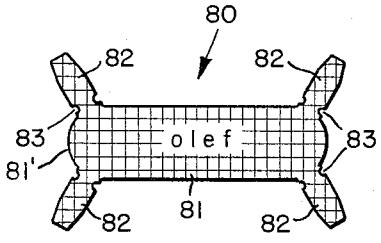


FIG. 7

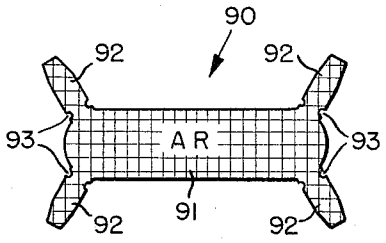


FIG. 8

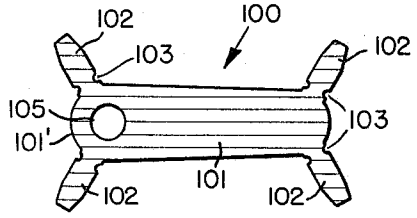


FIG. 9

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MODEL SET FOR REPRESENTING STRUCTURES OF CHEMICALS

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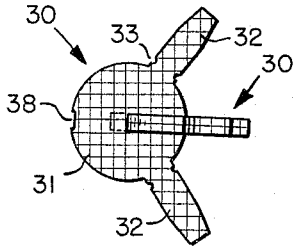


FIG. 18

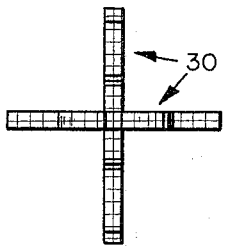


FIG. 19

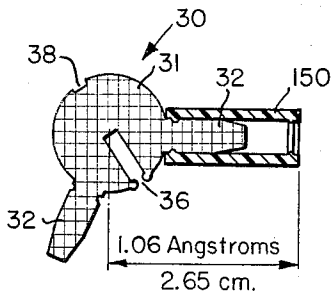


FIG. 20

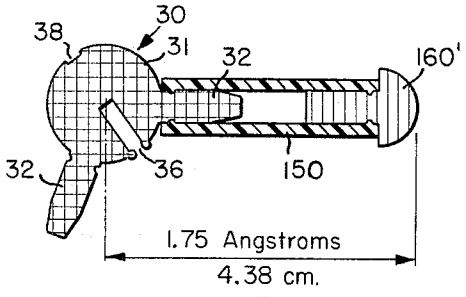


FIG. 21

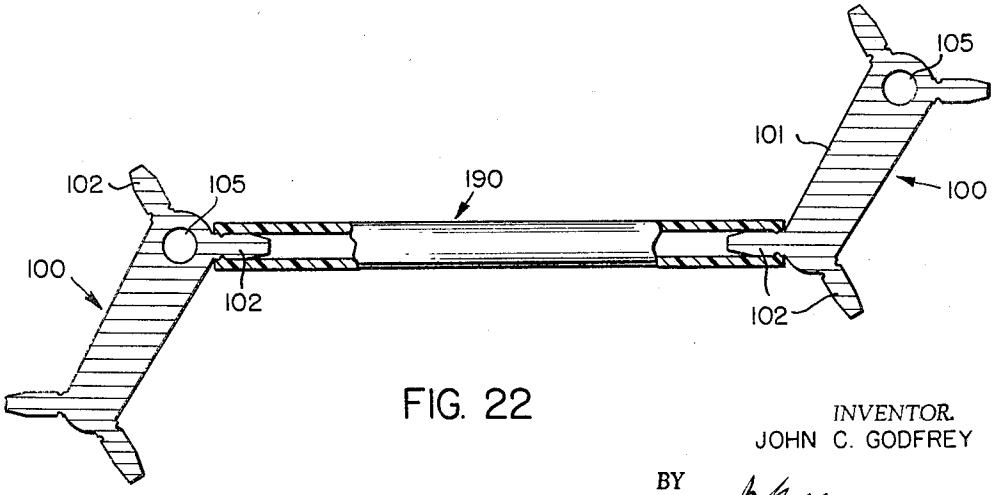


FIG. 22

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United States Patent Office 3,284,926
Patented Nov. 15, 1966

3,284,926

MODEL SET FOR REPRESENTING STRUCTURES OF CHEMICALS

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Filed Nov. 14, 1963, Ser. No. 323,803
14 Claims. (Cl. 35—18)

The present invention relates to models, and more particularly to structural models for depicting chemical compounds. In a still more specific aspect, the invention relates to a model set comprising a number of pieces, various of which represent different atoms or groups of atoms, and which are connectable to one another in various ways to illustrate the structures of different, more complex compounds, made up of such atoms or groups of atoms.

One object of the present invention is to provide models which accurately represent on a magnified scale the actual internuclear distances and bond angles in actual atoms and molecules, so that by scaling off the models, the actual internuclear distances and bond angles of the depicted molecules themselves can be determined by a student, or other interested party.

Another object of the present invention is to provide a model set in which the various pieces or units may be connected by connectors to form models of even the most complex molecular structures.

In this connection another object of the invention is to provide a design of connector for a model set of the character described which provides a stronger link between pieces than ordinarily found in chemical model sets.

Another object of the invention is to provide a connector design such that without undue effort the units or pieces can be disconnected when a model is disassembled.

A further object of the invention is to provide a model set for assembling a model of a chemical structure from a plurality of pieces, in which the connectors for the pieces are so constructed that there is no chance that wrong connectors will face one another when, for instance, an attempt is made to close a model of a heterocyclic ring.

Another object of the invention is to provide a model set which will permit constructing models of molecular structure in which the connectors for the pieces have built-in torsional friction. This is of especial advantage where the stereo-chemistry of open chains or flexible rings is concerned.

Another object of the invention is to provide a model set with connectors so constructed that the atoms may be rotated into any desired conformation and will remain there for accurate measurement of bond angles and internuclear distances.

Another object of the invention is to provide a model set of the character described in which the units have inherent flexibility so that compounds having several bonds can be accurately modeled in any conceivable situation.

A further object of the invention is to provide a model set of the character described in which the pieces can be deformed by a large amount without such deformation being permanent and without danger of breakage.

Other objects of the invention will be apparent hereinafter from the specification and from the recital of the appended claims, particularly when read in conjunction with the accompanying drawings.

In the drawings:

FIGS. 1 to 14 inclusive are views illustrating the configuration of different pieces in a model set made according to one embodiment of this invention; FIG. 1 is a

perspective view of a piece, while FIGS. 2 to 13 are side views of other pieces;

FIGS. 15 and 16 are two views, partly in section, showing how the insert stud of FIG. 14 can be connected to different tubular members to represent different molecular groups;

FIG. 17 is a view of one of the universal type connectors provided in the set;

FIGS. 18 and 19 are two views taken at right angles to one another and illustrating the assembly of two pieces, such as illustrated in FIG. 1, to represent a full atom;

FIG. 20 is a view, partly in section, showing assembly of two pieces to represent a specific molecule;

FIG. 21 is a view showing assembly of three pieces to represent another specific molecule; and

FIG. 22 is a view, partly in section, illustrating assembly of three other pieces to form still another molecule.

In the views the cross-hatching on the pieces, except for the tubular pieces, denotes the colors of the respective pieces.

The pieces of the model set of this invention are preferably molded from a flexible plastic material such as low-density polyethylene. They are intended to be engineered with extreme care to provide models which accurately represent internuclear distances and bond angles. The preferred scale of representation is 2.50 centimeters per angstrom, which is a magnification factor of 250,000,000. By making the pieces to such a scale it is possible to measure directly from the models internuclear distances.

The pieces are intended to be made in different colors and in different sizes, to represent, respectively, different atoms or molecules. Except for the tubular connectors all of the pieces are flat; and their areas are considerably greater than their thicknesses. Portions of the different pieces are, however, of corresponding size so that the pieces can readily be connected together in any desired relationship.

The pieces illustrated in FIGS. 1 and 2 are, for instance, similar in construction but are of different color and of different size except for radially projecting pegs. The piece **30** of FIG. 1, for example, may be black in color. It is flat and has a substantially circular central portion **31** from which there project radially two pegs **32**. The center lines of these pegs are radial of the center of the circular central portion **31**. Each peg **32** is recessed on its opposite sides, as denoted at **33** near the base of the peg, that is, near the juncture of the peg with the circular portion of the piece. The purpose of these recesses is to permit the connection of two or more pieces to provide three-dimensional models of the skeletons or structures of chemical compounds by interlocking opposed pegs on separate pieces by means of flexible plastic tubes such as shown at **35** in FIG. 17. Each of the pieces **30** has a slot **36** in it extending from the periphery of its circular portion inwardly to the center of that portion; and on the opposite sides of this slot at the outer end thereof are formed lugs or teeth **37** which are oppositely disposed and project toward one another and which serve to flexibly snap-lock pieces together. Diametrically opposite the slot **37** the piece **30** is formed with a shallow groove or recess **38**, which also serves for cooperatively locking pieces together, as will further be described hereinafter.

The piece **30**, for instance, may represent a half carbon atom and may be used in representing saturated carbon atoms as in alkanes, alcohols, carbon tetrachloride, and diamonds.

The piece **40** shown in FIG. 2 is similar to the piece **30** of FIG. 1. It has a central generally circular portion **41**, and radially projecting pegs **42**, which have notches **43** therein in opposite sides at their junctures with the central portion **41**. It has a radially extending slot **46** with

opposed teeth or lugs **47** at its outer end, and a diametrally opposite groove **48**. Its central portion **41**, however, is smaller in diameter than the central circular portion **31** of the piece **30**. Moreover, it may be blue, for instance, in color instead of black. It is intended to represent a different atom from that represented by the piece **30**, as for instance, a half nitrogen atom. The piece **30** may have a covalent radius of 0.76 measured in Angstrom units; whereas the piece **40**, may have a covalent radius of only 0.70 Angrstom unit. The bond angles, that is, angles between the radial center lines of the peg portions **32, 42**, of the two pieces may, however, be equal. As here shown, the angle is 109°28′. Two pieces, such as shown in FIG. 2, may be used with three connectors to show amines and ammonia. The fourth peg then represents an unshared electron. Two such pieces used with four connectors illustrate the structure of quaternary ammonium ions, and amine oxides.

Obviously, other pieces, like the pieces **30** and **40**, may be made in different diameters of their central portions and in different colors to represent other atoms or half atoms.

FIG. 3 shows a piece **50** having a generally circular central portion **51** and two radially-projecting pegs **52**. The central portion of this piece, however, is not slotted or notched. Its pegs, though, do have, like pieces **30** and **40**, recesses or notches **53** in opposite sides at their junctions with the circular central portion **51**. This piece may represent digonal or divalent oxygen, and may be red in color. The covalent radius of this piece is 0.66 Angstrom; and the bond angle between the center line of its peg portions **52** is slightly different from the bond angles of the pieces **30** and **40**; it is 105°. This piece may be used in building structures representing molecules of water, acids, alcohols, ethers, esters, oxides, and peroxides, etc.

FIG. 4 shows a piece **140** having a circular central portion **141** and pegs **142** displaced from one another at an angle of 104° around the circular portion. These pegs have, as in the case of other pieces, grooves **143** at their junctures with the circular portion of the piece. This piece has a covalent radius of 1.04 Angstrom units and may be yellow in color to indicate digonal or divalent sulfur. This piece may be used in making models of mercaptans, hydrogen sulfide, thioethers, etc.

The piece **60** of FIG. 5 has a generally circular central portion **61** from which there project three pegs **62**, spaced 120° apart. These pegs, like those previously described, have recesses **63** at their junctures with the central portion. The central portion of this piece, however, is not slotted or grooved. This piece may be colored black, for instance. Its covalent radius is 0.696 Angstrom unit. This piece may be used to represent trigonal or trivalent carbon, as contrasted with the piece **30** of FIG. 1 which can be used in representing tetrahedral carbon. The piece **60** may be used wherever the carbon atom carries two single and one double bond. Thus, it may be used in building up models of the molecular structure of benzene, allene, ketone, aldehydes, acids, esters, imines, and graphite-like structures.

The piece **70** of FIG. 6 is similar in construction to that of FIG. 5, but it has a covalent radius of only 0.656 Angstrom unit. Its peg **72** are, however, again spaced at a bond angle of 120° from one another. The pegs again have notches **73** in their opposite sides at their juncture with the central portion **71**. The piece **70** may be blue in color, and may be used to represent trigonal or trivalent nitrogen in the formation of models which represent heteroaromatic nitrogen, nitro, nitrose, nitrite, nitrate, azo groups, and any case of



purine, indole, pyridine, etc.

The piece **80** of FIG. 7 has an oblong central portion **81** with part-circular arcuate end portions **81′** at opposite ends from which pegs **82** project radially. The pegs **82** have notches **83** in their opposite sides at their junctures with the oblong body portion. The covalent radius of this piece is 0.696 Angstrom unit; and its internuclear distance is 1.34 Angstrom units. Its pegs at opposite ends are spaced 120° from one another. This piece may be colored black, for instance, and may have embossed thereon the legend "olef" to indicate that this piece represents an olefinic double bond. It may be used in building up the representation of a compound where an isolated, non-conjugated double bond is required.

The piece **90** of FIG. 8 is similar to the piece **80** of FIG. 6, the principal difference being that it is embossed with the legend "AR" to indicate a conjugated and aromatic double bond. It has an oblong body portion **91**, and pegs **82** at opposite ends, which project from circular arcuate portions which are spaced angularly at 120° from one another. These pegs again are notched on opposite sides as denoted at **93**. This piece, like the piece of FIG. 6, may be black, or any desired color. Its covalent radius is 0.696 Angstrom unit; and its internuclear distance is 1.395 Angstrom units. It is used in building up a molecule where a conjugated double bond is required, and in the construction of such compounds as naphthalene, phenanthrene, and other non-linear aromatic hydrocarbons.

The piece **100** shown in FIG. 9 is somewhat similar to the pieces **80** and **90** of FIGS. 6 and 7. However, the sides of its oblong portion **101** converge toward the right-hand end of the figure. It has pegs **102** at opposite ends which project from circular arcuate portions **101′** and are spaced 120° from one another. This piece may represent an amide group; and the larger end is intended to be the carbon end, and the smaller end the nitrogen end. The covalent radius of the carbon end is 0.696 Angstrom unit; while the covalent radius of the nitrogen end is 0.656 Angstrom unit. Its internuclear distance is 1.32 Angstrom units. The hole **105** is to identify the carbon end of the piece. The pegs have notches **103** in opposite sides as before. This piece may be used in the representation of all amides except B-lactams.

The piece **110** of FIG. 10 has a generally hollow hexagonal portion **111**; and its pegs **112** project from the apices of the hexagon. Again the pegs have grooves in opposite sides as denoted at **113**. The covalent radius of this piece is 0.696; and its internuclear distance is 1.395 Angstrom units. The piece shown is black in color. It represents a benzene ring; and it may be used wherever a six-membered aromatic ring is required, including use in building up models of pyridine, pyrimidine, and other heteroaromatics.

The piece **120** of FIG. 11 has an oblong main portion **121** which has arcuately curved portions **121′** at opposite ends that have pegs **122** projecting radially therefrom. These pegs are notched at **123** on opposite sides. This piece, as shown, is black. Its bond angle is 180° between the two pegs; and it has a covalent radius of 0.696 Angstrom unit. It represents an internuclear distance of 1.21 Angstrom units. And it may be used in the construction of models of acetylenes and cumulenes.

The piece **130** of FIG. 12 is generally hollow triangular in shape, as denoted at **131**. It has external circular arcuate portions, however, at each of the apices as indicated at **131′**. It has notches **133** at each of these external apices, and internal slots **135** aligned with the notches **133**. The piece shown is black, and is intended to be used with three pieces **30**, representing three half-carbon units, to represent cyclopropanes. It has a covalent radius in Angstrom units of 0.76, and an internuclear distance of 1.52 Angstrom units. The bond angle is 109°28′.

The piece **150** shown in FIG. 13 is a white tube having a covalent radius of 0.30 Angstrom unit, and may be used wherever hydrogen atoms appear in the molecule, or serve as connectors for carbonyl oxygen. This tube may

be of uniform diameter for its full length, or may have, as shown, an internal ridge **152** adjacent each end which is adapted to engage in the notches of the pegs of other pieces of the set to couple the tube to another piece. Where the tube is of uniform diameter from end to end it will be simply held by friction to the piece to which it is coupled.

FIG. 14 shows a flat insert or stud **160** having a round head **161** and a shank portion **162**. The stud shown is red in color, and has a covalent radius of 0.51 Angstrom unit. It has notches **163** in opposite sides of its shank adjacent the juncture of its shank and head. These are adapted to be engaged by the ridges **152** of tube **150**, for instance, to build up a model of a compound. It may be used in combination with the white tube **150** of FIG. 13 to represent carbonyl oxygen. It is used in the construction of models of acids, aldehydes, ketones, and N-, P- and S-oxides.

Various colored studs may be used in combination with tubes **150** to represent various groups or atoms. For instance, a stud **170**, which is yellow in color may be used in combination with a tube **150** to represent thionyl sulfur. The covalent radius of the combination is 0.94 Angstrom unit. The shank **172** of this stud is pressed into the tube **175**. This combination may be used wherever double-bonded sulfur is to be represented in the model of a compound.

Other colors of studs may be used with tubes **150** to represent other groups of atoms. For instance, a blue stud may be used with a tube **150'** somewhat longer than tube **150** to represent the nitrile group, as illustrated in FIG. 16. It may also serve as the terminal two N atoms of an azide group when attached to a trigonal nitrogen atom such as illustrated in FIG. 5. The covalent radius of this combination is 1.85 Angstrom units.

Likewise, fluorine may be represented by a colorless stud in a colorless tube; and chlorine may be represented by a green stud in a colorless tube, bromine by a brown stud in a colorless tube, iodine by a purple stud in a colorless tube, etc.

FIG. 17 shows a tube **35**, as already described, for connecting any two multivalent atoms in a model. This tube is preferably colorless and has an internal ridge **39** adjacent each end to snap into notches of a peg of any piece of the set to connect tube and pegged piece together. The bore of this tube is of the same diameter as the pegs **32**, **42**, **62**, **72**, **82**, **92**, **102**, **112**, **122**, and **142**. These pegs have all the same width, length, and thickness.

FIGS. 18 and 19 show how two of the pieces of FIG. 1, which represent carbon atoms, may be connected together by interlocking them. The two slots **37** of the two pieces **30** are pushed together until the teeth **37** of each piece snap into the small grooves **38** of the other piece. The assembly represents one complete tetrahedral carbon atom.

Similarly, a tetrahedral nitrogen atom may be assembled from two pieces **40** (FIG. 2) representing two half atoms.

Atoms or groups which have a valence in one direction only, except hydrogen, are represented by the hollow plastic tubes **150** of an internal diameter equal to the width of the pegs and of a neutral hue, such as white or colorless, and carrying clearly visible inserts **160** of colors coded to the atoms or groups which are to be represented, and cut to lengths such that the measurement from the center of the circular portion of the flat or tetrahedral units, which represent single atoms, to the extreme end of the color-coded identifying inserts provides an accurate measure of the corresponding internuclear distances as they actually occur in real molecules on the scale of magnification here used.

With the structures shown, the correct internuclear distance is represented in assembled units by the distance from the center of an atom model, for instance, to the extreme end of a tube mounted thereon, or to the extreme end of the tube plus insert where an insert **160** is used with a tube **150**. For instance, when a hydrogen tube **150** is mounted on one of the pegs of a piece **30** representing a half carbon atom, the internuclear distance is measured from the center of the portion **31** of piece **30** to the extreme end of the tube **150**. This is the distance of 2.65 cm. or 1.06 Angstroms (FIG. 20). Likewise, when a tube representing chlorine and having a green stud insert **160'** is mounted on one of the pegs **32** of the piece representing a half carbon atom, the internuclear distance can be measured and is 4.38 cm. or 1.15 Angstroms (FIG. 21).

Molecular skeletons or structures may be assembled by snapping individual atoms or groups of atoms together with the universal connectors **35**. The molecular skeletons may then be filled out by addition of pieces representing the appropriate hydrogen, oxygen, or halogen atoms. For hydrogen bonding, tubes can be cut to an appropriate length, and for this purpose, rubber tubing of ⅛ inch inside diameter can be used to represent the bonded hydrogen and oxygen atoms. Since the length of the hydrogen bonds varies from 2.4 A. to 3.2 A., depending upon the molecule, the tubing should be cut to the length corresponding to the hydrogen bond in the molecule under consideration.

FIG. 22 illustrates how two pieces **100** (FIG. 9) may be connected by a piece of tubing **190** of proper length to represent a polypeptid as an example. Here the tube **190** represents the hydrogen bond. It is 9.18 cm. in length. It connects one of the pegs **103** at the large end of one piece **100** with a peg **103** at the small end of another piece **100**. in FIG. 22, the internuclear distance (C— to N—) is the total of 2.93 A. (length of H-bond) plus 0.51 A. (covalent radius of carbonyl oxygen) plus 0.696 A. (covalent radius of trigonal carbon) equal 4.14 A. Multiplication of this value by the conversion factor 2.50 gives a total internuclear distance of 10.35 cm. Since the tube **190** does not go clear to the nuclei of the C and N atoms but stops at the circumference of the circular portions of the pieces representing these atoms, their combined radii, 0.53 cm. plus 0.64 cm., must be subtracted from the length of 10.35 cm., leaving an actual tube length of 9.18 cm.

The tubes **150**, **175**, **185**, **35**, etc are provided internally at opposite ends with ridges which provide snap-lock connections. These snap-lock connectors allow assembly and handling of large complex models, such as synthetic polymers or natural substances like proteins and polysaccharides without inadvertent disruption.

Through use of tubes and flat pegs, the pieces representing atoms may be rotated into any desired confirmation and will remain there for accurate measurement of bond angles and internuclear distances.

The use of single units to represent two or more atoms, as in the case of the pieces **80**, **90**, **100** and **130**, makes construction of models simple and rapid. Because of the inherent flexibility of polyethylene, only two types of carbon units **30** are needed to accurately model compounds having double bonds in any conceivable situation, such as cyclobutenes, exocyclic and endocyclic double bonds in five and six membered rings, as well as indenes and indoles.

Although construction of highly strained systems may deform some of the pieces by a large amount, this deformation is not permanent due to the resilience of the polyethylene; and there is no danger of breakage.

The acetylenic triple bond is an example of two atoms joined by one sigma bond and two pi bonds, and is represented by a single piece **120** (FIG. 11).

The tetrahedral nitrogen atom **40** (FIG. 2) serves a double purpose. In preparing models of ordinary alkyl, aryl, or mixed function, primary, secondary and tertiary amines, the fourth bond receptacle is left vacant and thereby represents the unshared pair of p-electrons. In ammonium salts or quaternary ammonium ions, the fourth bond receptacle is, of course, occupied by H— or R—, and the resulting model is of an ion with unit positive

charge. The trigonal nitrogen atom model correctly represents the condition of nitrogen in pyrrole, indole, azo, and oxidized nitrogen compounds.

Although the pyridine ring is nearly identical in dimensions to the benzene ring, it may be more explicitly shown by building it from one trigonal N piece **70**, one trigonal piece C **60**, and two double bond pieces **90**. The unoccupied bond receptacle on the nitrogen piece then represents the unshared pair of p-electrons, or may be used for quaternization (pyridinium compounds), or for attachment of a carbonyl oxygen piece to form a model of pyridine N-oxide.

The allenic linkage >C=C=C<, which has an internuclear distance between terminal carbon atoms of 2.59 A. (6.47 cm.) on the scale used here, is correctly represented by joining two trigonal carbon atoms by one of the nitrile group white tubes **150** from which the blue identifying insert **180** has been removed. In order to be accurate, one of the pieces **60** representing a trigonal carbon atom must be rotated 90° out of the plane of the other piece **60** representing the other trigonal carbon atom.

Enough hydrogen atoms may be provided in a set to saturate practically any structure which can be built with the set. However, usually it is found more convenient to leave off all but those hydrogen atoms between which it is desired to measure internuclear distances.

For hydrogen bond lengths other than 2.93 A. the appropriate value of length should be used. The resulting hydrogen bond representation is accurate, and at the same time realistic, in that the bond is both elastic and flexible. The bond may be made as strong as desired by wiring the ends of the tubing to the connected pegs.

Since all parts are made of polyethylene, they are insoluble in all common organic solvents, and may be cleaned with acetone or ethyl acetate.

Color coding is accomplished by uniform pigmentation of the bulk plastic before molding. The colors are, therefore, uniform and completely permanent.

While pieces **30** and **40** have been shown representing only tetrahedral carbon and tetrahedral nitrogen, respectively, it will be understood that by proper dimensioning of the central portions and proper coloring of the pieces, other pieces can be provided in a set which will represent tetrahedral silicon, tetrahedral phosphorus, tetrahedral sulfur, tetrahedral aluminum, tetrahedral titanium, tetrahedral iron, tetrahedral cobalt, tetrahedral nickel, tetrahedral germanium, tetrahedral arsenic, etc. The extremities of two half carbon atoms **30** or half nitrogen atoms **40** lie at the corners of perfect tetrahedra; and the other tetrahedral atoms will be similarly constructed.

The pieces **80**, **90**, **100**, and **120** are derived from two or more circular sections joined by substantially parallel lines; and the pegs **82**, **92**, **102**, and **122** of these pieces project from the circumference of said circular sections. The center lines of said pegs lie on lines passing through the centers of said circular sections.

The tubes **175**, **185**, **35** have internal diameter equal to the width of said pegs.

As stated, the tubes **35**, **150** are molded with internal integral rings of plastic at both ends. The purpose of these rings is to engage the recesses in the bases of the pegs, thereby to provide a firm, yet flexible connection between the independent units of a set of pieces.

When a tube is attached to the planar or tetrahedral units, which represent atoms or groups, by means of the connecting pegs, measurement from the center of the circular portion of the flat or tetrahedral unit, which represents a single atom, to the extreme end of the tube provides an accurate measure of the corresponding internuclear distance as it actually occurs in the real molecule on the scale of magnification used in making the model.

In the set the units to be represented may be chosen from the group consisting of the nitrile group, thionyl sulfur, carbonyl oxygen, fluorine, chlorine, bromine, and iodine.

Besides the units illustrated, other units may be provided in a set representing trigonal boron, trigonal oxygen, tetrahedral silicon, tetrahedral sulfur, tetrahedral titanium, tetrahedral cobalt, tetrahedral arsenic, tetrahedral phosphorous, tetrahedral aluminum, tetrahedral iron, tetrahedral nickel, tetrahedral germanium, octahedral magnesium, octahedral vanadium, octahedral iron, octahedral nickel, octahedral zinc, octahedral ruthenium, octahedral magnesium, octahedral chromium, octahedral cobalt, octrahedral copper, octrahedral molybdenum, octahedral rhodium, octahedral palladium, octahedral tungsten, octahedral irridium, octrahedral platinum, square coplanar cobalt, square coplanar copper, square coplanar palladium, square coplanar nickel, square coplanar platinum, linear silver, linear cadmium, linear mercury, etc.

The pegs **32**, **42**, etc. are of identical length but the substantially circular portions of the planar units and of the tetrahedral units vary in radius from atoms of one type to atoms of another type according to the well known covalent atomic radii which in Angstrom units for tetrahedral carbon are 0.76; trigonal carbon 0.696; digonal (acetylenic) carbon 0.696 on one side, 0.605 on the other side; tetrahedral nitrogen 0.70; trigonal nitrogen 0.656; diagonal oxygen 0.66; diagonal sulfur 1.04; hydrogen 0.30; carbonyl oxygen 0.51; thionyl sulfur 0.94; nitrile nitrogen 0.55; fluorine 0.60; chlorine 0.99; bromine 1.14; iodine 1.36; and according to the well known coordinate covalent radii which for octahedral complexes are: chromium O and II 1.32; chromium III 1.24; iron II 1.24; iron III 1.29; cobalt II 1.41; cobalt III 1.31; nickel II 1.40; copper II 1.33; ruthenium III 1.38; rhodium III 1.36; palladium IV 1.37; platinum IV 1.30; and which for square coplanar metal complexes are: cobalt II 1.49; nickel II 1.21; copper II 1.33; platinum II and IV 1.34; palladium II 1.33; and which for linear metal complexes are: silver I 1.45; cadmium II 1.24; mercury II 1.32; and which for tetrahedral metal complexes are: aluminum III 1.19 plus or minus 0.08; iron O and III 1.22; cobalt O 1.21; nickel O 1.21; germanium IV 1.16 plus or minus 0.04; and arsenic III 1.20 plus or minus 0.02.

While the invention has been described in connection with one embodiment thereof, it will be understood that it is capable of further modifications, and this application is intended to cover any variations, uses, or adaptations of the invention following, in general, the principles of the invention and including such departures from the present disclosure as come within known or customary practice in the art to which the invention pertains and as may be applied to the essential features hereinbefore set forth, and as fall within the scope of the invention or the limits of the appended claims.

Having thus described my invention, what I claim is:

1. A set for making models of molecular structures comprising a plurality of pieces, each of which is flat and has plane parallel sides, and each of which has at least one circular arcuate portion and at least one peg projecting radially therefrom, certain pieces having slots therein which extend radially of the axis of said arcuate portion, and which have parallel plane sides and a width equal to the thickness of other pieces, and which extend to said axis, to interfit with other like pieces to represent molecules composed of a plurality of like atoms.

2. A set as claimed in claim 1, wherein each of the said certain pieces has two lugs on opposite sides of its slot opposed to each other and disposed substantially at the junctures of the opposite sides of the slot and the circular arcuate portion of the piece, and each such piece also has a groove in the periphery diametrically opposite its said slot.

3. A set for making models of molecular structures comprising a plurality of pieces, each of which is flat and has plane parallel sides and each of which has at least

one circular arcuate portion and at least one peg projecting radially therefrom, one piece, at least, having an oblong portion and two circular arcuate portions at opposite ends, respectively, of said oblong portion, and at least one peg projecting from each arcuate portion radially of the axis of the respective arcuate portion.

4. A set as claimed in claim 3, wherein the sides of said ablong portion converge from one end to the other end thereof.

5. A set as claimed in claim 3, wherein there is but one peg projecting radially from each of said circular portions.

6. A set as claimed in claim 3, wherein there are a plurality of angularly spaced pegs projecting from each of said circular portions.

7. A set for making models of molecular structures comprising a plurality of pieces, each of which has at least one circular arcuate portion and at least one peg projecting radially therefrom, each peg having grooves in its opposite sides at the juncture of the peg with its circular portion, the pegs on different pieces being of the same length, width and thickness, and connector tubes being provided having an internal diameter equal to the width of the pegs, and the tubes having internal rings adjacent their opposite ends to engage in the grooves of pegs to lock the tubes.

8. A set of pieces for making models of molecular structures, comprising a plurality of pieces, each of which has pegs thereon, but which are of different shapes, and a plurality of tubes, each piece having a plurality of pegs integral with it and projecting from its perimeter, the pegs of all the pegged pieces being flat and having the same length, width and thickness, and the tubes having an internal bore diameter equal to the widths of the pegs whereby the pegs may be held in the tubes.

9. A set of pieces for making models of molecular structures, comprising a plurality of pieces, each of which has at least one generally circular portion, and each of which has a plurality of pegs projecting radially beyond the periphery of its circular portion, the pegs being all of the same width, length and thickness, but the circular portions being of different radii, whereby the pieces represent different atoms, and a plurality of tubes whose internal bore diameter is equal to the width of the pegs.

10. A set of pieces for making models of molecular structures, comprising at least two identical pieces, each of which has a central generally circular portion and at least two pegs projecting radially from said central portion, and each of which has a radial slot in its central portion, the two pegs of each piece being of equal length and being disposed at opposite sides, respectively, of its slot, and being equiangularly spaced therefrom, whereby the two pieces may be internested with one another so that the extremities of their pegs lie at the four corners of a perfect tetrahedron.

11. A set as claimed in claim 10, wherein each of said pieces has a recess in its central portion diametrally opposite its slot, each notch having opposed teeth on its opposite sides adjacent the outer end of the respective slot, to engage in the recess of the other piece.

12. A set of pieces for making molecular models comprising a plurality of flexible plastic pieces, each piece having at least one portion of generally circular shape, at least one piece having two circular arcuate portions joined by an integral intermediate portion, each piece having at least two pegs projecting radially from and beyond its circular portion, the center lines of said pegs being radial of said circular portions, said pegs having identical widths, lengths and thicknesses, and each peg having shallow recesses in its opposite sides adjacent its base, and a plurality of flexible plastic tubes, each of which has a bore diameter equal to the width of the pegs, and internal integral rings adjacent its opposite ends that are adapted to engage in said recesses to lock said tubes and pegs releasably together, thereby to enable pieces to be connected together by said tubes.

13. A set of pieces for making molecular models as claimed in claim 12, wherein different pieces are differently colored and have circular portions of different radii, respectively, to represent different atoms.

14. A set of pieces for making molecular models as claimed in claim 12, including additionally a plurality of colored inserts, each being flat and having a rounded head portion and a shank portion, the shank portions of said inserts being adapted to be inserted in the tubes to represent different groups of atoms, said pieces, inserts and tubes being sized so that measurement from the center of the circular portion of a piece to the outermost point on the head of an insert provides an accurate measure of the internuclear distance of the atoms represented by the interconnected part.

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