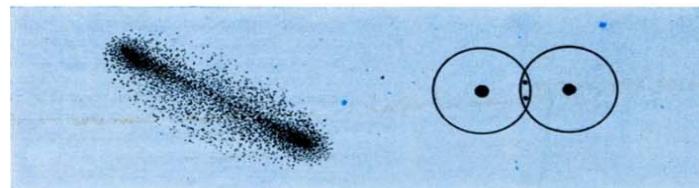


van der WAALS' Forces and Gravity

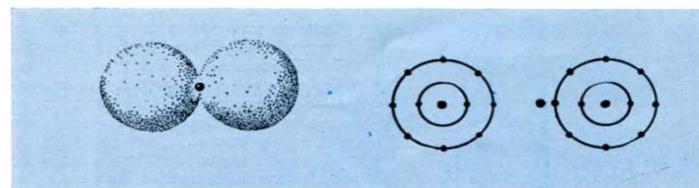
The *n-body Problem Closed-form Solution* may be readily applied in determining the sum of the attractive or repulsive forces between atoms and molecules, a subject generally of physical chemistry¹.



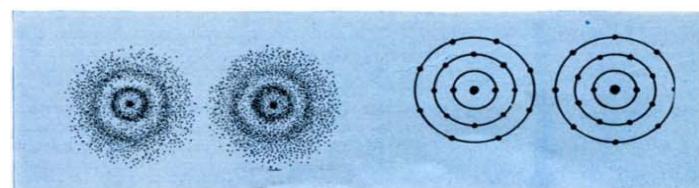
IONIC BOND is one of accepted relationships between atoms. Example: sodium chloride. At left is crystal arrangement of sodium and chlorine. At right is diagram of electron structure. Ions are held by electrostatic charge.



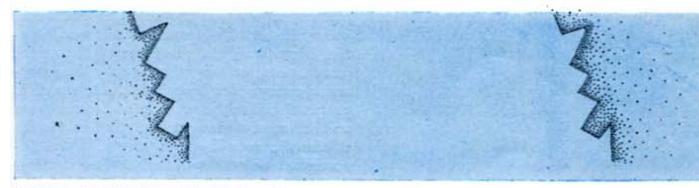
COVALENT BOND entails the sharing of two electrons by two atoms. The simplest example is the hydrogen molecule, H_2 . At left is electron cloud model of molecule; at right is diagram of its two nuclei and two electrons.



HYDROGEN BOND utilizes the stripped nucleus of hydrogen as a bridge between two negative ions. In this case the positive hydrogen nucleus (dot between atoms in diagram at the right) links two ions of fluorine.



VAN DER WAALS FORCE is a weak attraction between atoms. Example is the noble gas argon, which forms no chemical combinations. Nucleus of one atom has slight attraction for electrons of the other, and vice versa.



LONG-RANGE FORCE is believed by some to exist between two widely separated large molecules. Here two protein molecules are shown in highly schematic diagram. Interacting molecules have mold and cast configuration.

Figure 1: Chemical Bonds and Molecular Forces

1 See Reference: "Long-Range Forces," by Thaddeus STERN: sketch is from that article.

Overview

Thesis: *all electromagnetic field forces emanating from atomic nuclei — weakly pass beyond their outermost valence electrons — are responsible of gravity.* This includes neutral **van der WAALS** and like forces, but excludes all other direct chemical bonding forces and those owing to covalent bonds. These gravitational field forces are effected via “*force-at-distance*” forces.

The observed, neutral **van der WAALS** forces may be just those forces causing gravity. And there is more than sufficient physical evidence of these minute electromagnetic field forces (for whatever their name) passing beyond the valance electrons (see **STERN**'s article below). “*Gravity*” in this case meaning nuclei forces attracting other unattached, neutral electrons. This root, microscopic cause-and-effect relationship, echoes **NEWTON**'s famous problematic macroscopic recognition and final acceptance of observed “*forces-at-distance*” phenomena.

Three types of microscopic attractive forces are known to exist between neutral molecules: dipole-dipole forces, **LONDON** (or dispersion) forces, and hydrogen bonding forces [see Ref: **EBBING**, pp. 418-424]. In chemistry the term “**van der WAALS forces**” is a general term for those intermolecular forces, and includes *dipole-dipole* and **LONDON** forces. The term **van der WAALS forces** is assumed here to be even more general — macroscopic — as forces effected interactive between all neutrally detached bodies.

Some preliminary definitions²:

- **Bonding force:** force holding two atoms together; it results from a decrease in energy as two atoms are brought closer to one another.
- **Covalent bond:** a primary bond arising from the reduction in energy associated with overlapping half-filled orbitals of two atoms.
- **Dipole moments:** a dipole moment is a quantitative measure of the degree of charge separation in a molecule. See “**Dipole Moments**,” in Volume 4, pp. 479-483, of the 1968 Edition of the **Encyclopædia Britannica**.

² Definitions extracted form **Little & Ives Complete Book of Science Illustrated**, 1963.

- **Ionic Bond:** a primary bond arising from the electrostatic attraction between two oppositely charged ions.
 - **LONDON forces:** are the weak attractive forces between molecules resulting from the small, instantaneous dipoles occurring because of the varying positions of the electrons during their motion about nuclei.
 - **Quantum Mechanics:** a branch of physics wherein the systems studied have only discrete energy levels, separated by forbidden regions. It is distinguished from *continuum mechanics* in which a continuum of energies is assumed possible.
- **Valence electron:** An electron in the outer shell of an atom. Such electrons are called valence electrons because, by gaining, losing, or sharing these outer-shell electrons, atoms combine to form molecules. Therefore, the number of these outer-shell electrons often determines the valence or valences of the atom; although there are many instances in which an atom acquires a higher positive valence than the number of electrons in its outer shell, by losing also electrons from its next to outer shell.
- **Valence force field:** an assumed force field utilized to solve the equation in which the potential energy of vibration of a polyatomic molecule is expressed in terms of the energies of the restoring forces of each atom and the energies of their interaction terms. This simplify assumption implies a force constant is associated with every valence bond and every valence angle, representing their resistance to change in length or magnitude.
- **van der WAALS Forces:** interatomic or intermolecular forces of attraction owing to the interaction between fluctuating dipole moments associated with molecules not possessing permanent dipole moments. These dipoles result from momentary dissymmetry in the positive and negative charges of the atom or molecule, and on neighboring atoms of molecules. These dipoles tend to align in anti-parallel directions and thus result in a net attractive force. This force varies inversely as the seventy power of distance between ions.
- **Wave Mechanics:** a branch of mathematical physics involving the statements and solutions of differential equations describing wave behavior.

Long-Range Forces

LONG-RANGE FORCES

Alexandre Rothen's proposal that they may account for specific chemical reactions between molecules that are not in contact has begun a heated debate

by Thaddeus Stern

OUR concept of the chemical behavior of all matter is founded on the assumption of intimate interactions among molecules. One molecule encountering another of a different kind enters into some sort of direct physical contact with it; it may unite with, reshape, split or completely disrupt the second molecule, and fundamentally this process is supposed to account for all chemical change, including life itself.

For some time, however, biologists have been puzzled by indications of a strange kind of molecular behavior that does not fit this accepted picture. Certain molecules, for instance those in the threadlike chromosomes of living cells, appear to affect one another at a distance in some mysterious way that cannot be explained by existing theory. And recently Dr. Alexandre Rothen of the Rockefeller Institute for Medical Research has aroused considerable interest among biologists and physicists by reporting experiments which, he concludes, actually demonstrate such long-range molecular interactions.

Dr. Rothen suggests that the most likely interpretation of his experiments is that there are specific long-range forces acting between molecules, and that chemical action between large molecules is possible even though they are very far from contact with one another! This is such a revolutionary idea that it has become the focus of much controversy.

Rothen's experiments deal with serum, antibodies, antigens and monomolecular films. A brief explanation of these terms will help make his experiments clear.

Blood consists of liquid plasma in which are suspended several different kinds of cells, including the oxygen-bearing red cells and various white cells. If the cells are removed from blood without clotting, plasma remains. If clotting is allowed to occur, however, a clear yellowish fluid is obtained. This is serum. Plasma and serum differ from each other principally in the fact that plasma lacks the clotting protein fibrinogen. Serum contains a number of inorganic salts and organic compounds, including various large protein molecules. Among these proteins, which form about seven per cent of the serum, are albumin and a number of globulins.

When an animal is injected with a foreign protein (antigen), it tends to produce

a modified native protein (antibody), which has the remarkable property of combining specifically with the antigen. It is therefore called the homologous antibody for this particular antigen. The antibodies, protein molecules that play an important role in immunity to infectious disease, are found to belong with the so-called gamma fraction of the globulins.

Unlike organic molecules in the class of esters, sugars and so on, which contain a dozen to at most a hundred atoms, protein molecules have thousands of atoms. They are arranged around a coiled or folded chain structure, not unlike that of the synthetic molecules such as Nylon. Thus antibodies are conceived to have the shape of long, thin chains. The current view is that in the process of formation these chains can fold into a large number of different configurations.

If a molecule of antigen happens to be present during the synthesis of a protein in the living organism, it may shape the protein molecule by acting as an important organizing factor in the environment. Such a mechanism might well account for the highly specific nature of antigen-antibody reactions; the antigen and its homologous antibody fit each other like a mold and its cast. Specific and selective chemical action of this sort is a striking and characteristic property of biological substances. It is found not only in serum reactions but also in the interaction of enzymes and hormones with other substances, in the reproduction of genes, and so on.

At Rockefeller Institute Rothen has studied serological reactions between monomolecular films of antigens and their homologous antibodies. Films which are one molecule thick can easily be obtained with some substances on a clean water surface. An example of such a substance is stearic acid. Each stearic acid molecule contains a water-soluble (hydrophylic) section and a water-insoluble (hydrophobic) section. If a small drop of a dilute solution of stearic acid in benzene is placed on a water surface which has been skinned clean, the benzene evaporates and the molecules of stearic acid align themselves with the hydrophylic ends in the water and the hydrophobic ends out of it. A monomolecular film is thus formed, and it can be compressed, ex-

panded or transferred to a flat polished slide for further study.

Similar films can be prepared with proteins. Protein films, however, spread themselves in a somewhat different way. In their usual shape, protein molecules have thicknesses of the order of 25 to 100 angstroms (one angstrom = $1/100,000,000$ centimeter), but on a water surface they form films which are only 6 to 10 angstroms thick, whatever their molecular size may be. This smaller thickness corresponds roughly to the average cross section of the protein's extended chain structure. Thus in the process of spreading on the water surface the coiled or ellipsoidal shape of the native protein molecule has been unfolded into a new and thinner configuration.

UNFOLDING impairs or even destroys the biological activity of proteins in some cases but not in others. Films of some pituitary hormones, for example, lose most of their hormone activity, while films of the hormone insulin remain fully active. Films of egg albumin and of serum albumin from human beings, horses and cattle all retain their full ability to react with their homologous antibodies.

Rothen's much-discussed experiments have been carried out mostly with films of albumin from cattle, which retain their serological activity very well. The homologous antibody for his work was obtained by injecting this bovine albumin into rabbits and using the resulting rabbit serum containing the antibody for bovine albumin.

In the experiments Rothen uses a rectangular trough filled to the brim with water. The water surface is first skinned clean by sliding a polished, chromium-plated metal bar over the top of the trough. Films of the antigen (bovine albumin) are then spread on the surface. The films can be compressed by sliding other bars over the trough surface. They may then be transferred to a flat, polished, chromium-plated slide by dipping the slide vertically into the water. If the film is picked up on the downward movement of the slide, the hydrophobic side of the film faces the slide and the hydrophylic side remains exposed; if it is picked up on the upward motion, when the slide is drawn out of the water, the sides are re-

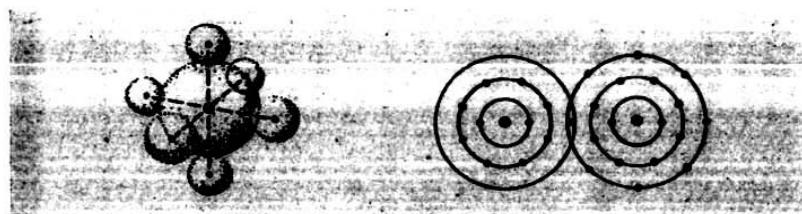
versed. A "round trip" dipping results in the transfer of a double film, presenting a hydrophobic or a hydrophylic outer surface, depending on whether the trip is started from above or below the water surface. Many alternating films can thus be picked up on one slide, and it is also possible to pick up a series of "down" films or of "up" films by spreading a new film for each dip.

After this process has been completed, the antigen-covered slides are brought into contact with a solution of serum containing the antibody. The slides are then rinsed (without washing off the films) and dried. Now comes the crucial part of the experiment: measurement of any change that may have occurred in the films' thickness. Since all of Rothen's deductions are based on these observations, his method for making accurate measurements should be described.

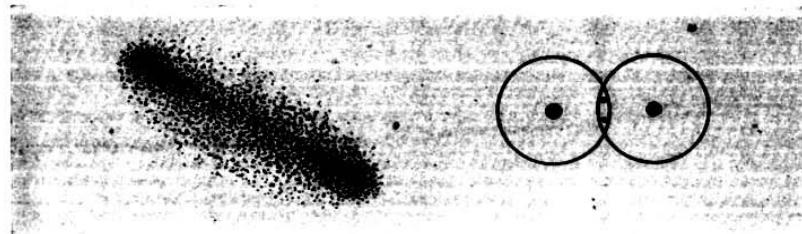
Because the existing techniques for determining the thickness of films were relatively crude, with an uncertainty of 15 to 30 per cent, Rothen designed a special instrument, the ellipsometer. The operation of this instrument is based on the fact that linearly polarized light is elliptically polarized when it is reflected from a metal surface. The shape and angle of the ellipse of polarization depend on the angle of incidence of the light and on the optical constants of the metal. A thin, transparent film alters the optical constants in proportion to the film's thickness. Rothen's ellipsometer measures the degree of this alteration.

To use the ellipsometer as a measuring instrument, a metal slide is first coated with an "optical gauge" as a standard or point of reference. For this purpose, the clean, polished slide is covered with one or more films of barium stearate, a compound that forms films of known thickness. Half of the slide then is covered with two additional layers of the same film. The difference in thickness of the films covering the two halves of the slide results in a difference of ellipticity of the light reflected from these two half fields. Consequently when they are viewed through the ellipsometer they appear of unequal intensity. By rotating a polarizing filter in the ellipsometer, the intensity of both half shadows can be equalized. The corresponding angle is then recorded as the zero reading for the slide before films of unknown thickness are measured. These need be deposited only on the central part of the gauge-covered slide. The added layers disturb the original optical balance, and the angle of rotation of the polarizing filter that is required to restore equal shadow intensity is a measure of the thickness of the added film, accurate to within one third of an angstrom.

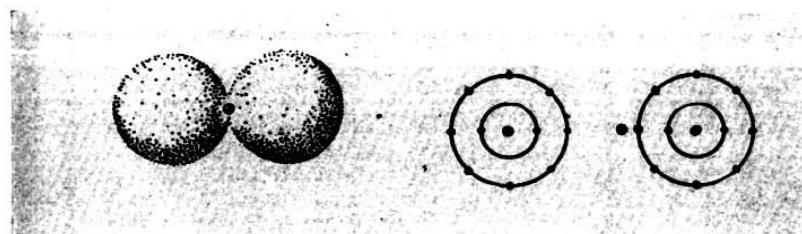
Rothen found that films of bovine albumin on his slides, after being treated with rabbit antiserum containing the homologous antibody, increased in thick-



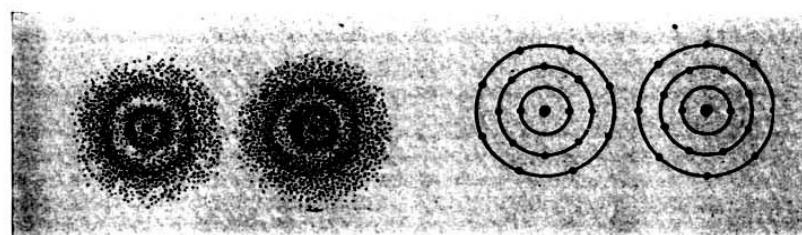
IONIC BOND is one of accepted relationships between atoms. Example: sodium chloride. At left is crystal arrangement of sodium and chlorine. At right is diagram of electron structure. Ions are held by electrostatic charge.



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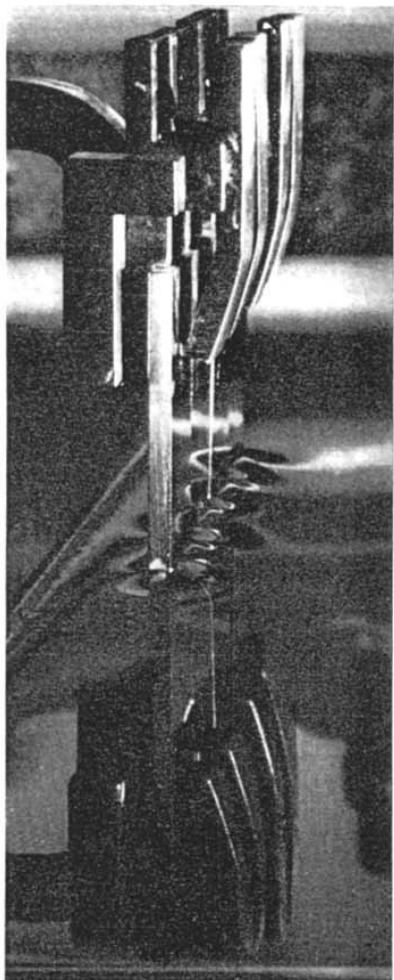
HYDROGEN BOND utilizes the stripped nucleus of hydrogen as a bridge between two negative ions. In this case the positive hydrogen nucleus (dot between atoms in diagram at the right) links two ions of fluorine.



VAN DER WAALS FORCE is a weak attraction between atoms. Example is the noble gas argon, which forms no chemical combinations. Nucleus of one atom has slight attraction for electrons of the other, and vice versa.



LONG-RANGE FORCE is believed by some to exist between two widely separated large molecules. Here two protein molecules are shown in highly schematic diagram. Interacting molecules have mold and cast configuration.



SLIDES are dipped in a tank of water to coat them with monomolecular film. Film floats on water surface.



"BLANKET" of plastic is rectangle floating on water. Slide bearing antigen film is pressed down upon it.

ness by an amount that was consistent with the estimated size of the antibody molecules. Treatment with normal, antibody-free serum resulted in very little or no increase in thickness. This observation merely shows, of course, that the antigen in the films retained its specific ability to combine with the antibodies; the antibodies which thus became bound to the antigen caused the thickening of the films.

Rothen also found, however—and this is the surprising fact—that if the antigen films were covered with films of barium stearate, of the plastic Formvar or of other materials that might have been expected to act as a screen, subsequent treatment with antiserum still resulted in an increase of thickness, even though the screens in some cases were several hundred angstroms thick. In other words, the antigen and antibody appeared to be able to interact even through a barrier between them! The influence of the barriers depended mainly on their thickness and very little, if at all, on their nature, except that any metal film thick enough to be continuous blocked the activity. Perhaps more surprising still is Rothen's additional observation that the increase in thickness was greater if more than one layer of antigen was deposited on the plate. It increased in direct proportion to the number of such layers. It also depended on the orientation of the films, i.e., on whether the hydrophylic or hydrophobic side was uppermost.

It was to account for these unexpected results that Rothen made his assumption of specific long-range forces operating between molecules, at least in the case of oriented films. The distances involved here are on a microscopic scale, of course, but the phenomena observed are so surprising, in view of the current theory about how molecules should behave, that the distances might as well be astronomical.

LET us consider the historical context of this proposition. The phenomenon of action at a distance perplexed the earliest philosophers. Speculation about the behavior of celestial bodies led the Greek philosophers Democritus and Epicurus to vague hypotheses of the tendency of the earth and the stars to a common center. Later, Johann Kepler, Galileo, and others assumed the existence of a mutual attraction between the sun, the earth and other planets. This assumption Isaac Newton formalized in the law of universal gravitation, stating that every body attracts every other body by a force which is proportional to the product of their masses and inversely proportional to the square of the distance between them. When investigators discovered that action at a distance also manifested itself between electric charges, Charles Augustin de Coulomb was able to formulate his well-known electrostatic law, which is in form quite anal-

ogous to Newton's law of gravitation but which accounts for repulsions as well as attractions at a distance, depending on whether the electric charges are of similar or of opposite sign.

These gravitational and electrostatic forces, and the later discovery of magnetic forces, provide a satisfactory explanation of physical action at a distance. But they fail completely to provide any theoretical hint to account for the remarkable specificity of the biochemical reactions of the type described by Rothen.

There is a type of intermolecular attraction produced by short-range forces known as the van der Waals forces, named for the Dutch physicist Johannes van der Waals, who discovered them. These are believed to result from the mutual interaction between the electrons of one atom and the nucleus of another. This attraction seems to be slightly greater in strength than the force of repulsion of electrons by electrons and nuclei by nuclei; hence it accounts for short-range attractions between molecules.

Another well-known type of molecular or interatomic force is the so-called hydrogen bond. This bond is formed by a bare hydrogen nucleus stripped of its single electron. The positively-charged nucleus tends to attract electrons and thus acts as a bridge between an atom in one molecule and an atom in another. It is weaker than an ionic bond, in which two atoms of opposite electric charge are attracted to each other; or a covalent bond, in which two electrons are shared by two atoms; but it is stronger than a van der Waals force.

It is possible for at least some of these well-known forces to transmit their influence to considerable distances through effects in intermediate atoms and molecules, but physicists have not been able to formulate any such mechanism that could account for the specificity required to explain Rothen's results.

This dilemma has resulted in considerable controversy among scientists. Let us therefore scrutinize Rothen's assumptions. He assumes that his films remain essentially flat and that antigen or enzyme molecules do not get through the screening barriers. But his measurements of the thickness of the films are no proof at all of the validity of these assumptions. His measurements give only the average thickness of the films; they leave open the question of whether there are places where the antigen films are not completely covered and molecules can get through.

Linus Pauling of the California Institute of Technology has suggested, and many physicists and chemists agree, that it is highly probable that Rothen's assumptions are not valid and that actual atomic contact takes place between the interacting molecules. On the other hand, Rothen's experiments have been repeated and confirmed at the research laboratories of the General Electric Company. Irving

Langmuir of General Electric, the English physicist J. D. Bernal and others believe that the experiments actually do demonstrate chemical reactions at a distance.

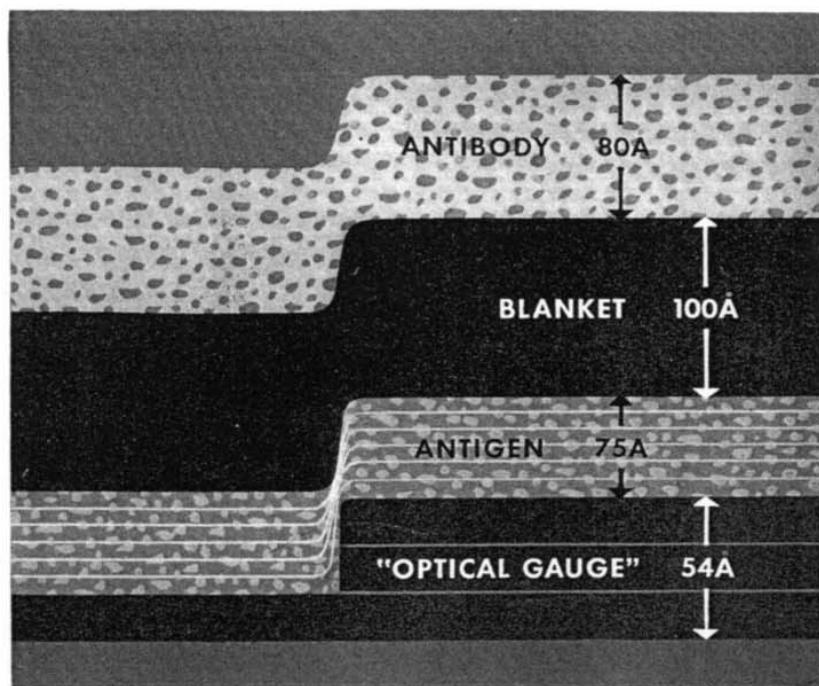
Recently the question was discussed by a number of eminent scientists at a symposium of the Polytechnic Institute of Brooklyn under the chairmanship of Peter J. W. Debye. The discussion considered two possibilities: 1) that there might be holes in the barriers; 2) that the underlying antigen film might buckle or clump in such a way as to create sharp peaks and valleys; the screening materials might well fill the valleys but leave the peaks exposed.

Rothen pointed out that if the "hole" theory were correct, it would take some time for the molecules to diffuse from one layer to another, and that different screens would be expected to give different sizes and concentrations of holes and therefore different times. He found no such effects. As for the "peak and valley" theory, he thought it improbable, since a single film of barrier material fully protected a film of insulin from the action of the relatively small protamine molecule, with which insulin readily reacts. It is possible, however, that insulin films may not buckle while bovine albumin films may. In fact, electron microphotographs were shown which clearly indicated the presence of peaks in bovine albumin films. Similar photographs made by Rothen, however, showed the peaks to be insufficiently high, in his opinion, to sustain this objection. He also reported that separately prepared barriers of Formvar, which were shown to be free of holes, gave the same results as liquid deposits of Formvar films.

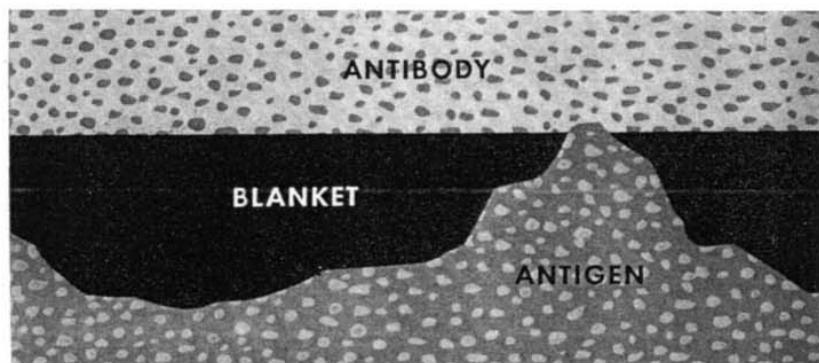
Evidence for what appear to be long-range forces between the large rod-shaped molecules of tobacco mosaic virus has been presented by Dr. I. Fankuchen of the Polytechnic Institute of Brooklyn. In X-ray studies made together with J. D. Bernal in England, he found that the virus molecules remained parallel to one another, with an endwise hexagonal arrangement, in swelling gels of the substance. L. Onsager of Yale University has presented a theory to account for this phenomenon, however, on the basis of the elongated shapes of the molecules and of short-range forces, without invoking new long-range forces. But no application of this theory appeared to be able to account for Rothen's film experiments.

And so the dilemma stands. Further work will show whether Rothen's assumptions are valid or not. If they are, his revolutionary concept of specific chemical action at a distance will require many readjustments in the thinking of physical chemists.

Thaddeus Stern is the pen name of a well-known investigator in the field of physical chemistry.



CROSS-SECTION drawing of Rothen experiment shows relationship of films. Optical gauge (standard for thickness measurement), antigen and blanket are deposited. If antigen sticks to blanket, interaction has occurred.



POSSIBLE FLAW in the Rothen experiment is that the layer of antigen is not smooth, but has peaks and valleys. A few of the peaks might then remain exposed above the blanket and thus would react with the layer of antibody.



ANOTHER FLAW proposed in the experiment to explain Rothen's observations is that the blanket might be punctured with holes, permitting the layers of antigen and of antibody to come into contact with each other.

van der **WAALS'** Forces

The following was extracted from the excellent *wikipedia* article on **van der WAALS'** forces³: in physical chemistry, the **van der WAALS'** force (or **van der WAALS'** interaction), named after Dutch scientist Johannes Diderik **van der WAALS** (1837-1923), is the sum of the attractive or repulsive forces between molecules (or between parts of the same molecule) other than those owing to covalent bonds, the hydrogen bonds, or the electrostatic interaction of ions with one another or with neutral molecules or charged molecules⁴. The term includes:

- force between two permanent dipoles (**KEE SOM** force)
- force between a permanent dipole and a corresponding induced dipole (**DEBYE** force)
- force between two instantaneously induced dipoles (**LONDON** dispersion force).

It is also employed loosely sometimes as a synonym for the totality of the intermolecular forces. **van der WAALS'** forces are relatively weak compared to covalent bonds, but play a fundamental role in fields as diverse as supra-molecular chemistry, structural biology, polymer science, nano- technology, surface science, and condensed matter physics. **van der WAALS** forces define many properties of organic compounds, including their solubility in polar and non-polar media.

In low molecular weight alcohols the hydrogen-bonding properties of the polar hydroxyl group dominate the weaker **van der WAALS'** interactions. In higher molecular weight alcohols, the properties of the non-polar hydrocarbon chain(s) dominate and define the solubility. **van der WAALS** forces quickly vanish at longer distances between interacting molecules.

In 2012, the first direct measurements of the strength of the **van der WAALS'** force for a single organic molecule bound to a metal surface was made via atomic

3 See: http://en.wikipedia.org/wiki/Van_der_Waals_force

4 **Compendium of Chemical Terminology**, 2nd Ed., **IUPAC** (aka, the "Gold Book"), 1997. Online 1994 corrected pdf version: "van der WAALS forces"

force microscopy and corroborated with density functional calculations⁵.

van der **WAALS'** Forces Between Macroscopic Objects

The following was extracted from the *wikipedia* article too: for macroscopic bodies with known volumes and numbers of atoms or molecules per unit volume, the total **van der WAALS** force is often computed based on the “*microscopic theory*” as the sum over all interacting pairs. It is necessary to integrate over the total volume of the object, which makes the calculation dependent on the objects' shapes. For example, the **van der WAALS'** interaction energy between spherical bodies of radii R_1 and R_2 , and with smooth surfaces, was approximated in 1937 by H. C. **HAMAKER**⁶ (using **LONDON**'s famous 1937 equation for the dispersion interaction energy between atoms/molecules⁷ as the starting point) by:

$$U(z; R_1, R_2) = -\frac{A}{6} \left(\frac{2R_1 R_2}{z^2 - (R_1 + R_2)^2} + \frac{2R_1 R_2}{z^2 - (R_1 - R_2)^2} + \ln \left[\frac{z^2 - (R_1 + R_2)^2}{z^2 - (R_1 - R_2)^2} \right] \right) \quad (1)$$

where A is the **HAMAKER** coefficient, which is a constant ($\sim 10^{-19} - 10^{-20}$ J) which depends on the material properties (it can be positive or negative in sign, depending on the intervening medium), and z is the center-to-center distance; i.e., the sum of R_1 , R_2 , and r (the distance between the surfaces): $z = R_1 + R_2 + r$.

In the limit of close-approach, the spheres are sufficiently large compared to the distance between them; i.e., $r \ll R_1$ or R_2 , so equation (1) for the potential energy function simplifies to:

$$U(z; R_1, R_2) = -\frac{AR_1 R_2}{(R_1 + R_2) 6r} \quad (2)$$

5 See: http://www.columbia.edu/~sva2107/media/Aradhya_NMat_2012.pdf.

6 H. C. **HAMAKER**, *Physica*, 4(10), 1058-1072 (1937).

7 F. **LONDON**, *Transactions of the Faraday Society*, 33, 8-26 (1937)

The **van der WAALS'** force between two spheres of constant radii (R_1 and R_2 are treated as parameters) is then a function of separation since the force on an object is the negative of the derivative of the potential energy function,

$F_{vw}(r) = -\frac{d}{dr}U(r)$. This yields:

$$F_{vw}(r) = -\frac{AR_1R_2}{(R_1 + R_2)6r^2} \quad (3)$$

The **van der WAALS** forces between objects with other geometries using the **HAMAKER** model have been published in the literature^{8, 9}.

It is seen from the expression above the **van der WAALS** force decreases with decreasing particle size (R). Nevertheless, the strength of inertial forces, such as gravity and drag/lift, decrease to a greater extent. Consequently, the **van der WAALS** forces become dominant for collections of very small particles such as very fine-grained dry powders (where there are no capillary forces present) even though the force of attraction is smaller in magnitude than it is for larger particles of the same substance. Such powders are said to be cohesive, meaning they are not as easily fluidized or pneumatically conveyed as easily as their more coarse-grained counterparts. Generally, free-flow occurs with particles greater than about 250 μm .

The **van der WAALS'** force of adhesion is also dependent on the surface topography. If there are surface asperities, or protuberances resulting in a greater total area of contact between two particles or between a particle and a wall, this increases the **van der WAALS** force of attraction as well as the tendency for mechanical interlocking.

⁸ For a more in-depth overview, and more references, of molecular structural calculations see Per-Olov LÖWDIN article "**Molecular Structure Calculations**", in **Encyclopedia of Physics**, 2nd Ed., edited by Rita G. LERNER and George L. TRIGG, VCH Publishers, pp. 753-759, 1991.

⁹ 1) TADMOR, R: **JOURNAL OF PHYSICS: CONDENSED MATTER**, 13 (2001) L195-L202; 2) ISRAELACHVILI J.: **Intermolecular and Surface Forces**, Academic Press (1985-2004), ISBN 0-12-375181-0; 3) 11. PARSEGIAN, V. A.: **van der WAALS Forces: A Handbook for Biologists, Chemists, Engineers, and Physicists**, Cambridge University Press. 2006. ISBN 978-0-521-83906-8

The microscopic theory assumes pairwise additivity. It neglects many-body interactions and retardation. A more rigorous approach accounting for these effects, called the “macroscopic theory,” was developed by **LIFSHITZ** in 1956¹⁰. **LANGBEIN** derived a much more cumbersome “exact” expression in 1970 for spherical bodies within the framework of the **LIFSHITZ Theory**¹¹, while a simpler macroscopic model approximation had been made by **DERJAGUIN** as early as 1934¹². Expressions for the **van der WAALS** forces for many different geometries using the **LIFSHITZ Theory** have likewise been published.

The extracted portion of the wikipeadia article ends here.

10 E. M. **LIFSHITZ**, *Soviet Phys. JETP*, 2, 73 (1956).

11 D. **LANGBEIN**, *Phys. Rev. B*, 2, 3371 (1970)

12 B. V. **DERJAGUIN**, *Kolloid-Z.*, 69, 155-64 (1934)

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2. BAEYER, Hans Christian von: **Taming the Atom, The Emergence of the Visible Microworld**, Dover, 1992. Good background material.
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