presents a paper and receives the award at the summer meeting of the association following the annual meeting at which it was voted. The recipient of the award for 1941 is Herald R. Cox.

"Cultivation of Rickettsiae of the Rocky Mountain Spotted Fever, Typhus, and Q Fever Groups in the Embryonic Tissues of Developing Chicks," Herald R. Cox, Rocky Mountain Laboratory, Hamilton, Montana.

Life at High Altitudes and Aviation Medicine. Anton J. Carlson, The University of Chicago, *chairman.* Tuesday morning, September 23.

Contributors: Carlos Monge, University of San Marcos, Peru; David Bruce Dill, U. S. Army; E. S. Guzmán Barrón, The University of Chicago.

Thoracic Diseases. Dallas B. Phemister, The University of Chicago, *chairman.* Thursday morning, September 25.

Contributors: Clayton G. Loosli and William E. Adams, The University of Chicago; Evarts A. Graham, Washington University; John Alexander, University of Michigan; Oswald H. Robertson and Robert G. Bloch, The University of Chicago.

Sex Hormones. Frank R. Lillie, The University of Chicago, *chairman.* Friday morning, September 26.

Contributors: Carl R. Moore and Allan T. Kenyon, The University of Chicago; Edward A. Doisy, St. Louis University; John S. L. Browne, McGill University; Fred C. Koch, The University of Chicago.

Immunological Mechanisms. George F. Dick, The University of Chicago, *chairman.* Friday morning, September 26.

Contributors: William Bloom, The University of Chicago; Linus C. Pauling, California Institute of Technology; Thomas M. Rivers, The Rockefeller Institute for Medical Research.

THE SECTION ON EDUCATION (Q)

Environment and Education. Robert J. Havighurst, The University of Chicago, *chairman.* Monday morning, September 22.

Contributors: Ernest W. Burgess, The University of Chicago; Franz Alexander, Institute for Psychoanalysis, Chicago; W. Lloyd Warner, The University of Chicago; Margaret Mead, American Museum of Natural History.

The Conceptual Structure of Educational Research. Guy Thomas Buswell, The University of Chicago, *chairman.* Tuesday afternoon, September 23.

Contributors: Thomas R. McConnell, University of Minnesota; Douglas E. Scates, Duke University; Frank N. Freeman, University of California.

COLLOIDS IN ASTRONOMY AND METEOROLOGY

By JEROME ALEXANDER
NEW YORK, N. Y.

THE slight, irregular motion of tiny particles approximating the limits of microscopic resolvability was named in honor of Robert Brown, a Scotch botanist, who first drew attention to this phenomenon in 1827. Since non-living particles exhibit Brownian motion, there were many speculations as to its cause. It was often called "pedesis," because the particles seemed to "walk" about, and as early as 1896 Sir William Ramsay connected it up with the kinetic theory by expressing the view that there was a gradual transition between particles in gases or in solution, and particles in suspensions. The discovery of the ultramicroscope in 1903 by Richard Zsigmondy brought visual proof of the correctness of this view, for it brought into *visibility* particles as small as 5 mμ (five millionths of a millimeter). Since such submicroscopic particles are smaller than the wave-lengths of visible light, they can not be resolved, although they may be seen as "points" of varying degrees of luminosity and of Brownian activity. Calculations by Perrin, Einstein, Smoluchowski and others proved that the nature of the motion seen was what the kinetic theory demanded for particles of this size. Similarly, in the astronomical field, the discs of the sun and the moon may be resolved visually, and even small telescopes will resolve the larger planets; but not even the most powerful telescopes can resolve any of the fixed stars.

While no natural arbitrary limits exist for particles in what we now term the colloidal state of dispersion, these limits are, roughly, between 100 and 5mμ; that is, they begin just about the zone of microscopic resolvability and run down to dimensions commonly attributed to large molecules. It must be emphasized that particle size, that is, degree of subdivision or dispersion, is the criterion for colloidality, and that consequently, any substance, irrespective of its chemical constitution, may exist in the colloidal state. It is even possible to have colloidal crystals, and Scherrer demonstrated by x-ray analysis that colloidal gold particles at the lower ranges of the colloidal dimensions are crystalline.

As particles become smaller and smaller, the Brownian motion, just noticeable at the lower microscopic limits, increases very greatly in speed and amplitude; for kinetic motion depends (among other factors) on the mass; and, assuming spherical shape for convenience of calculation, the *mass* varies inversely as the *cube* of the diameter of the particle if no change in specific gravity accompanies dispersion. On the other hand, the *surface* of the particles varies inversely with the *square* of their diameters. The subjoined diagram indicates that in passing downward through the colloidal zone, we go from a condition where kinetic motion is relatively negligible as compared with the specific surface (that is, free surface per unit of weight), to a condition where the kinetic motion is of great importance, despite the large increase in specific surface. There thus naturally arises a *zone of maximum colloidality,* wherein the consequences of specific surface become most manifest before the consequences of kinetic motion become dominant. For example, maximum hardness in steel corresponds, approximately, to a colloidal dispersion of the iron carbide (cementite) in the iron. Both 5 per cent. starch suspensions and dextrose solutions show but slight increase in viscosity over water, whereas 5 per cent. starch colloidally dispersed, *e.g.,* by boiling, is very viscous. The importance of the zone of maximum colloidality in biology and medicine has been stated thus:[1]

> A most striking example of optimum dispersion is found in living matter. Figuratively speaking, if all the chemical substances comprising our organism were in true or crystalloid dispersion, reactions would proceed so rapidly that we would, so to say, live ten years in ten minutes. On the other hand, if coarse dispersion prevailed, it would take ten years to live ten minutes. Every organism is dependent upon the coordination of its chemical reactions *in point of time,* and this leisurely procedure depends largely upon *degree of dispersion,* which keeps chemical reaction velocities within certain speed limits through its regulation of free surface and kinetic activity. Life lies between lysis and coagulation. The colloidal zone is, as it were, a vital metronome, tolling off the tempo of life.

The extensive literature of colloid chemistry shows how large a number of factors influence the behavior of colloid particles, apart from the important one of size. For example, though for convenience we assume the particles to be spherical, they might have shapes widely differing from spheres. The specific gravity, chemical specificity and electric charge of particles and the nature of the medium in which they are dispersed are all of importance in determining their behavior. This literature also shows how wide-spread and important is the colloidal state on our relatively minute earth. It is only natural that we should expect to find instances of colloidal dispersion throughout the immensity of space, that is, in the field of astronomy.

An outstanding instance of the zone of maximum colloidality appears in the case of comets, whose nuclei, comas, and tails consist in part of colloidal matter. In 1870 J. Clerk Maxwell pointed out that the intensity of action of the sun's rays on a particle is in proportion to the particle surface which varies as the *square* of the particle diameter, whereas the gravitational pull of the sun on the particle varies as its mass which is proportional to the *cube* of its diameter. Theoretically, with particles having the density of water, the repulsion due to "light pressure" balances the solar attraction due to gravitation when the particles have a diameter of 0.0015 mm ($1.5\,\mu$). As particle size diminishes, the repulsive force gains domination over gravity, reaching a maximum and again diminishing, until with particles having a diameter of only 0.00007 mm (70 $m\mu$) the two forces once more balance each other. These limiting dimensions must be still further reduced in the case of particles denser than water, so that it would appear that the sun selectively repels colloidal particles to form cometary tails, which, as spectroscopic observations indicate, shine mainly by reflected sunlight. The comet's tail is, therefore, an extremely tenuous celestial camouflage, a vast Faraday-Tyndall effect, analogous to what a searchlight beam shows in a foggy or dusty atmosphere. The earth recently passed through a comet's tail without appreciable effect, although yellow journals prophesied dire consequences and members of a certain sect gathered in church to await the impending "end of the world" and last judgment.

According to calculations by Schwarzschild, the effects of light-pressure are insignificant on particles having the dimensions of gas molecules, when compared with the effect of gravity. More recently, P. Debye[2] confirmed Schwarzschild's conclusions by making an extensive re-analysis of this problem, basing his calculations on the classical radiation theory and upon the electron theory of Lorenz. This indicates that colloidal particles are selectively repelled by the sun, both larger masses and gases tending to be attracted. Most comet's tails show the spectra of nitrogen and of carbon monoxide, while cyanogen and carbon do not appear to extend much beyond the cometary head. We know little of the formation and stability of chemical compounds under the conditions of temperature and of electronic and mechanical turmoil which prevail when a comet approaches the sun and develops a tail; but we do know that colloidal "smokes" tend to "hold" gases and were, in fact, used for this purpose to "carry" gases during the world war.

Though very exceptional, heliocentric tails, that is,

[1] Jerome Alexander, "Colloid Chemistry, Theoretical and Applied," Vol. I, p. 25. Chemical Catalog Company, 1926.

[2] *Ann. der Physik.,* 30: 57–136, 1909.

tails pointing toward the sun, are known and, according to Professor N. T. Bobrovnikoff (Ohio Wesleyan University), were seen in Comets 1844 III, 1862 III and 1882 II. Such tails might consist of particles larger or smaller than colloidal dimensions, and in the former case would support the view of Bredichin that they are responsible for meteoric showers.

Matter in colloidal dispersion also finds place in the planetesimal hypothesis advanced by T. C. Chamberlin and F. R. Moulton to account for the formation of the solar system. According to this hypothesis, which finds wide acceptance, about ten or twenty billion years ago a star approached our sun closely enough to tear loose and send whirling through space a small percentage of the sun's mass. No direct "side-swiping" was needed, for the nearest approach of the visiting star may have been of the order of the earth's distance from the sun; but the enormous gravitational fields probably caused explosive or pulsating ejection of matter from both sun and star. Part of this fell back into the sun, part was carried off by the visitor as it departed after a "visit" of several months, and part, estimated as about one seventh of one per cent. of the total solar mass remained swirling about the sun in the direction of the visitor's exit, and irregularly distributed because of the explosive and pulsating nature of its ejection. This accounts for the more or less orderly spacing of the planets, for their uneven sizes, as well as for the fact that they all rotate in one direction and approximately in the same plane. The retrograde moon of the large planet Jupiter seems to represent a "capture," possibly a small comet, a large meteorite or other invader.

The ejected matter was probably initially gaseous for the most part, but as it cooled it condensed into larger and larger particles, which then accumulated into planets and satellites under the action of localized gravitational forces. In passing from gaseous to microscopic dispersion the colloidal zone must be traversed, and frequently colloidal particles persist indefinitely. So-called "cosmic dust" appears to be of such nature, and the enormous "dark nebulae" appear to consist of vast clouds containing colloidally dispersed matter, which, by obscuring the light of exterior bodies and systems, make the so-called "coal holes" which astronomers find in the heavens. Enormous amounts of finely dispersed matter are still being gathered in by the gravitational pull of the sun and the planets. The study of radioactive phenomena has so enlarged our notions of time that according to Professor F. K. Morris the Cenozoic period is pushed back to at least 50 million years ago, while our oldest visible rocks go back about to 1,500 million years.*

* See also H. N. Russell, SCIENCE, 92: 19 (July 12, 1940).

The solar corona, in its outer ranges, may have colloidally aggregated matter of evanescent life, and according to Professor H. N. Russell the galactic nebulae also contain colloidal material, although the brighter spiral nebulae, which are at much vaster distances, consist of aggregations of stars.

The zodiacal light may represent an aftermath of the birth of the solar system, for it consists of a cloud of tenuous matter shining by reflected solar light. Saturn's rings appear to be more concentrated, for they cast shadows and their solid content is estimated to be 2 to 3 per cent. of their volume. But the constant attrition of solid chunks in Saturn's rings, in cometary heads, as well as the occasional collision of bodies in space and the aggregation of radiated matter, all furnish renewed supplies of finely dispersed material. Colloidal particles must appear and must be given consideration. Colloidal dispersions of matter in the aether of space have been termed *aethersols,* in contra-distinction to colloidal dispersions in our atmosphere which are known as *aerosols.* Apart from their importance in meteorology, aerosols are of considerable military and commercial significance.[3]

From the standpoint of meteorology aerosols fall into two groups: *organic* material, such as bacteria, spores, pollen and vegetable fragments; *inorganic* material, such as water and ice, rock and soil particles, volcanic ash, meteoric and cosmic dust, salts from drying of sea-spray, and hydrated nuclei of various chemical compounds like nitric oxide, ammonia, hydrogen peroxide, sulphurous and sulphuric acid, which may be formed in the atmosphere by solar radiation, or by electric discharges, or else enter it as a consequence of combustion of fuel. The ever recurring evaporation of water and its condensation through the colloidal zone into liquid or solid form, takes place on a gigantic and continuous scale.

According to Dr. W. J. Humphreys our atmosphere is coincident with the konisphere (dust sphere), and contains the following layers:[4]

(1) *Turbulence layer,* approximately one kilometer in height, which can often be seen from mountain tops as a haze with a more or less sharply defined upper surface.

(2) *Convection layer,* in which thermal convection is marked. "Its upper surface, often three kilometers, roughly, above the earth, frequently is a sharply horizoned ocean, as viewed from an aeroplane, in which cumulus clouds stand like islands in the sea."

(3) *Troposphere,* extending to the level of the highest clouds; in our latitude approximately 10 to 12 kilometers, though it tends to be higher in equatorial regions and lower toward the poles. Because of its great height its

[3] Jerome Alexander, *Popular Astronomy,* 33: No. 7, 1925.

[4] W. J. Humphreys, Alexander's "Colloid Chemistry, Theoretical and Applied," Vol. I, p. 424.

upper surface is seldom seen but is indicated by certain polarization phenomena of skylight. Into this tropic layer, vertical convection due to sudden temperature changes, sometimes brings terrestrial dust.

(4) *Stratosphere,* comprising everything above the tropic layer. Colloidal particles coming from the "daily millions of meteors," from hygroscopic nuclei, and from dust hurled to enormous heights by violent volcanic eruptions, supply nuclei for the highest cirrus clouds.

According to Dr. Humphreys, the weather records of the past three centuries show that cloudy and cool summers followed on explosive volcanic outbursts. In 1815 a great eruption of Tomboro (Sumbawa Island in the East Indies) killed 12,000 persons, and the next year (1816) is known as the "year without a summer," for there was snow in June and in August. The explosive eruption of Krakatoa (1889) traveled thrice around the earth according to barometric records, and for several years the high-flung dust caused "golden sunsets." The lava of the Tomboro eruption has been estimated at six cubic miles, whereas Professor Wilbur A. Nelson calculated that during the Cretaceous period a now extinct volcano in Kentucky spat up 50 cubic miles of lava, whose fall may be traced 800 miles north and south, and 450 miles east and west of the crater. We can readily understand how in ages of great volcanic activity the climates and rainfall throughout the earth must have been seriously affected, even to the extent of glaciation. In 1932 ash from Chilean volcanoes reached as far as Rio de Janeiro in four days, a distance of 1,800 miles, and marked weather disturbances were reported in Argentine.[5]

The quantities of dust carried by winds is much greater than most people would imagine. They are sufficient to delay the twilight, for example, at Assuan in upper Egypt, for about 45 minutes. In March, 1901, a cyclonic storm central over Tunis raised dusts from the Algerian deserts to such high levels that one third of the 1,800,000 tons that fell in Europe dropped north of the Alps. About 150,000,000 tons are estimated to have fallen on the African coast, and an unknown amount into the Mediterranean Sea. Dust storms in Peiping are notorious, the dust clogging fountain pens, obscuring printed pages and causing what is called "Peiping throat." In the spring of 1934 some 300,000,000 tons of earth were lifted from the drought-parched western states by a strong northwest wind and scattered over half of our country. The legendary "Sea of Darkness" lying between the Canary and Cape Verde Islands is accounted for by the dust falls from Sahara, common there between January and April.

The incidence of goiter and cretinism, mainly due to iodine deficiency, is highest in regions remote from the sea, where salt dust formed by the drying of ocean spray is less apt to reach soil and water, and furnish the small but essential traces needed for the formation of thyroxin in the thyroid gland. It would take a person about 1,000 years to drink enough of the water of Lake Superior to give him the necessary supply of iodine, so that we can understand the importance of the unseen colloidal salt particles in our atmosphere.[6]

Weather conditions are, to a large extent, determined by the nature of the dispersion of water in the atmosphere; and to a considerable degree, the presence of condensation nuclei control water dispersion, and local conditions lead to the formation of haze, mist, fog, rain, snow or hail. The high incidence of dense fogs in London is largely attributable to the presence of nuclei resulting from the burning of coal, etc. Professor Carl Barus[7] kept a continuous record of atmospheric nucleation for several years at Providence, R. I. He found that the number of nuclei varied from about 2,000 to 100,000 per cubic centimeter; and though it varied greatly during each day as well as from day to day, it was much greater, on the average, about the time of the winter solstice when most fuel is burned, and least about the summer solstice. The most effective nucleators are substances which produce highly dispersed, hygroscopic or soluble particles. If fog be formed on such nuclei and then evaporated, the hydrated nuclei persist and will determine fog formation without material supersaturation. The luminous "paths" whereby one follows the emission of radium "rays" consist of strings of tiny water droplets deposited on strings of ionized particles, so numerous as to appear to be a continuous line in the Wilson fog-chamber. Nuclei are produced in quantity by brush discharges and even by impinging water jets.

When air containing moisture is cooled, supersaturation occurs and the moisture tends to condense. For example, in Hawaii the warm moist trade winds, in rising to pass over the high mountains, are cooled by expansion as the pressure is thus reduced, and thick clouds and heavy rains occur in the mountain tops and higher valleys; but the clouds evaporate as they move on, over the crests. Showers from a cloudless sky, locally known as "liquid sunshine," occur when the wind is strong enough to blow the mountain rain into a cloudless area. This is common in Honolulu. Cloud streamers are common on very high mountain peaks, *e.g.,* the Matterhorn; and in 1936 a "plume" seven miles long was observed streaming from Mt. Everest. Similarly, in the arctic regions, despite the small moisture content of the air, the intense cold

[5] Jerome Alexander, "Colloid Chemistry," 4th ed., D. Van Nostrand Company, 1937.

[6] *Ibid.*

[7] Carl Barus, Alexander's "Colloid Chemistry, Theoretical and Applied," Vol. I, p. 420.

produces very curious phenomena. Thus Rear Admiral Richard E. Byrd reports that the small amount of moisture held by air at 50 degrees below zero (F.) forms a real fog when thrown out by mixture with colder air; and "when a man stood inside the entrance to one of the house tunnels, the vapor formed by his breathing was so heavy the house appeared to be on fire."[8]

The raindrops which determine the formation of rainbows are much larger than colloidal dimensions, and so, in most cases, are the tiny ice crystals which cause halos about the sun, rings about the moon and the numerous other allied phenomena known to meteorologists. However, in many cases colloidal dispersions form, even though they may have a transient existence. "Solar rainbows," often seen in the tropics and just recently seen here, are due to very high floating ice particles. Finely dispersed particles are responsible for the "blue" color seen in certain lakes and portions of the ocean, in highly dilute emulsions or suspensions (*e.g.*, of milk), in glacial streams and possibly in glaciers. In 1913 Professor W. H. Martin[9] carefully freed liquids and gases from dust and found that they would scatter light. This was direct experimental proof of the theory of Lord Rayleigh that the blue color of the sky is due to scattering of light by air molecules, which are, of course, much below colloidal dimensions. In nature, however, liquids and gases are always contaminated with dispersed impurities, and these often exert a marked effect. In the absence of atmospheric dust, night descends abruptly, in contrast to the delayed twilight before referred to.

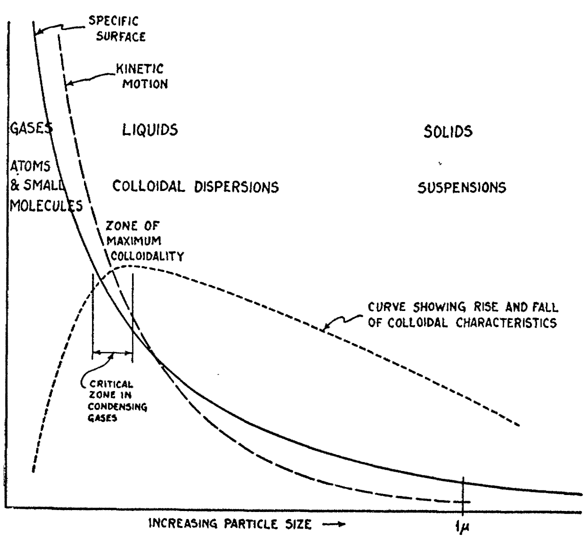

Fig. 1.

Colloidal haze causes a glare which prevents perception of distant detail, but which may be filtered out so that better vision is had through the long-wave fog-piercing portion of the spectrum. The use of neon lights for beacons, and infrared photography involve recognition of the fact that the amount of light scattered from its course is inversely proportional to the fourth power of its wave-length. Sunset and sunrise colors are mainly yellows and reds, whereas distant mountains often appear blue. In his story "Rip Van Winkle" Washington Irving refers to the fact that the appearance of the Catskill Mountain is a weather indicator to be relied on.

Clouds generally carry electric charges due to the capture of ions, electrons, surface electrification, etc. Since the charge is carried on the surface of the droplets, their aggregation, evidenced by development of a dark or livid shade, leads to very high voltages which can break down intervening resistance and form a lightning flash. In 1875 Gaston Planté produced globular brush discharges which sometimes formed wandering globular sparks. He pointed out that "ball lightning" involves the same principles, and stated: "Although an aqueous surface is not indispensable for forming luminous electric globules, since we have obtained them over a metallic surface, the presence of water, or of vapor from water, at least facilitates their formation or tends to give them more volume because of the gases furnished by the decomposition of water at high temperatures." J. C. Jensen recently reported that ball lightning occurs most frequently in connection with dust, *e.g.*, from a fire-place or in a squall or tornado. The explosive effects so often reported, seem to involve an oxyhydrogen explosion, which would be all the more violent if atomic hydrogen (Langumir) were first produced.[10]

Thomas Graham, F.R.S., the father of modern colloid chemistry, in commenting on the colloidal characters of ice at or near its melting point, points out that although ice formed at temperatures a few degrees under the freezing point has the well-marked crystalline structure seen in snow or hoar frost, ice formed in contact with water at 0 degrees C. is a plain homogeneous mass with a vitreous fracture, exhibiting no facets or angles. The beautiful crystals recently demonstrated in ice blocks by Sir William H. Bragg may, perhaps, be due to a molecular rearrangement, which Graham gives as an explanation of the observation of Mr. Persons that ice cooled below 0 degrees C gives off heat. After referring to Funke's "blood-crystals" which form in a highly colloidal material, Graham concludes: "Can any facts more strikingly illustrate the maxim that in nature there are no abrupt transitions, and that distinctions of class are never absolute?"

8 Jerome Alexander, "Colloid Chemistry," 4th ed.
9 W. H. Martin, Alexander's "Colloid Chemistry, Theoretical and Applied," Vol. I, p. 340.
10 Jerome Alexander, "Colloid Chemistry," 4th ed.