worked out previously in these laboratories by F. Gray[5] and independently by R. Holm.[6] The theory gives as an approximate formula

$$T = \text{const.} \frac{V^2}{K_o/\sigma_o} \qquad (3)$$

where T is the increase of temperature above room temperature, V the contact voltage and (K_0/σ_0) the ratio of the thermal to electrical conductivity of the contact material. A reasonable value of (K_0/σ_0) for carbon is obtained from these experiments. The conduction process is thus shown to be that which occurs in solid carbon, and no other effect, such as electronic discharge across small gaps, can be an important factor. This result is therefore in line with recent experiments of Holm[7] which have demonstrated the metallic nature of contacts between metals, and of carbon for relatively large contact forces.

The following experimental results have a direct bearing on the mechanism of change of resistance with change of contact force. Reversible resistance changes accompanying changes of contact force between fixed limits are obtained with these contacts, the resistance decreasing with increase of force. Also, the temperature coefficient of resistance is found to be substantially constant as the resistance is varied over a wide range in such a reversible cycle. Both these facts point to area change as the cause of the change of resistance with force, since we know that the elastic deformation of a contact would produce a change in contact area of the required type, and also since we might expect a measurable change in the temperature coefficient of resistance if the state of strain within the contact region were markedly altered. Although the mean stress within the contact area alters somewhat with the contact force, even when the area changes in accordance with elastic theory, this effect is relatively small.

These conclusions concerning the nature of the contacts and the mechanism of resistance change with contact force are in line with the assumptions underlying Gray's equation. Accordingly a study was made of the slopes of the reversible resistance force cycles for both single contacts and aggregates.

The technique used for the study of aggregates was similar to that employed for the single contacts with the exception that the lower contact C_1 consisted of a shallow cup with a conducting bottom and containing a large number of loosely packed granules several layers deep. The upper contact was made by cementing a large number of granules to the bottom of a conducting plate, the cement being such as to give a low resistance contact.

The experiments showed that for any reversible cycle the relation between the resistance and force was of the form

$$R = K\,(F)^{-n} \qquad (4)$$

in the case of both single contacts and aggregates. The exponent n varies somewhat from cycle to cycle when the force limits are the same and its average value depends on the force limits.

The largest values of n were obtained with the aggregates under such conditions of force limits as to indicate that the elastic straining of the aggregate during the cycle was relatively large. A maximum mean value substantially independent of the force limits over a wide range closely approaches 7/9, which is the maximum value consistent with equation (2). This indicates that with sufficiently large strains the aggregate may be made to act as though it were a single contact between spheres having rough surfaces obeying the laws assumed in the derivation of equation (2). On the other hand, for relatively small strains the value of n diminishes to values smaller than the theoretical minimum 1/3 consistent with equation (2). The measured values of n for single contacts are in general less than 1/3 and may become very small if the contact forces are large. These departures from theory appear to be associated with internal contact forces or cohesion which render the contacts relatively insensitive to changes in the applied forces. The existence of cohesion was readily demonstrated by the fact that the contacts always required a finite force to break them even when no current had passed through the contact.

All the experimental results are therefore consistent with the theory of area change due to the elastic deformation of the contact material. Furthermore, the realization of the theoretical maximum value of n in the case of the highly strained aggregates indicates that in a granular mass deformed elastically not only do the contact areas change in the case of those contacts already established, but that new contacts possibly between other granules may be made and broken in a reversible cycle.

OBITUARY

MEMORIAL TO JAMES MELVILLE GILLISS

THE Secretary of the Navy has forwarded to the Ambassador at Santiago, Chile, a bronze bust of the late Lieutenant James Melville Gilliss, U. S. Navy. Mrs. Louise Kidder Sparrow, of Hyannis, Massachusetts, was the sculptress. Congress on June 9, 1930, passed an act providing an appropriation to procure for presentation to the Chilean National Observatory,

[5] Unpublished.
[6] *Z. tch. Phys.*, 3: 290–294, 320–326, 349–357, 1922.
[7] *Wiss. Ver. a. d. Sieman's-Konzern*, 7: 217–271, 1929.

through the Secretary of the Navy, in the name of the United States Naval Observatory, a bronze bust of the late Lieutenant Gilliss, whose memory is honored by officials of Chile.

According to information sent from the Navy Department, Lieutenant Gilliss was the first to conduct a working observatory in the United States and to give his whole time to practical astronomical work. He published the first volume of observations and prepared the first catalogue of stars and planets compiled in the United States.

Lieutenant Gilliss was born in Georgetown, District of Columbia, September 6, 1811. He entered the United States Navy as a midshipman at the age of fifteen and served on the U. S. S. *Delaware*, ship-of-the-line, the *Concord* and the *Java* until 1831, when he was promoted to the rank of passed midshipman. He spent a year at the University of Virginia and later studied in Paris. In 1837, he succeeded Lieutenant Charles Wilkes, who was organizing his expedition to the Antarctic, in charge of the Depot of Charts and Instruments then located in Washington, D. C., on a site about 1,000 feet north of the Capitol.

In 1842, a bill was passed by Congress authorizing the establishment of an astronomical observatory and Gilliss prepared the plans for the building and arranged for the instruments. The site of the new building, the Naval Observatory, was on Braddock Hill, where the Washington, D. C., Naval Hospital is now located, 23d and 25th Streets between E Street and Potomac Park, N. W.

Gilliss's connection with astronomical observations, covering the period from 1838 to 1842, brought him in contact with Dr. Gerling, of Marburg University. Dr. Gerling proposed a new method of deducting the solar parallax from observations of Venus taken from points as far apart as possible in opposite hemispheres, but nearly on the same meridian.

These requisite physical conditions suggested to Gilliss that the obvious place for the other observatory was in Chile. His efforts finally brought authorization for funds from Congress, the project awakening world-wide interest, and he was assisted in his plans and assembling of equipment by some of the most prominent scientists of the day.

Upon the completion of the new observatory in Washington, Gilliss was assigned to duty on the Coast Survey in reducing for its use the entire series of moon-culminations previously observed and published by him. From November, 1848, to 1852, he was engaged in making observations for the determination of the solar parallax.

In August of 1849 he sailed for Valparaiso at the head of a scientific expedition. He located at Santiago, Chile, where he found atmospheric conditions, the necessary physical comforts and availability of repair facilities ideal. The Chilean Government rendered every assistance to Lieutenant Gilliss. There he completed a series of observations of great value. He likewise accumulated a vast amount of information concerning earthquakes and other subjects.

When Gillliss's work was finished, the interest he had awakened in astronomy did not flag. Chileans desired to found a National Observatory. The observatory which Gilliss had established was turned over to Chile as the Chilean National, hence the Chileans' affectionate reference to Gilliss as "the father of astronomy in Chile."

He visited Peru in 1858 to observe the total eclipse of the sun and in 1860 observed a total eclipse of the sun in the Washington Territory. In 1861, he was assigned to take charge of the Washington Naval Observatory. He died in Washington, D. C., in February, 1865.

RECENT DEATHS

DR. ELLWOOD HENDRICK, curator of the Chandler Chemical Museum of Columbia University and author of many books popularizing chemistry, died on October 30, at the age of sixty-eight years.

DR. HORACE E. STOCKBRIDGE, formerly director of the Indiana Experiment Station and from 1890 to 1894 president of the North Dakota Agricultural College, died on October 30, aged seventy-three years.

DR. PRESTON M. HICKEY, head of the department of roentgenology of the University of Michigan, died on October 30. He was sixty-four years old.

THE death at the age of eighty years is announced of George McLane Wood, for twenty-five years editor of the United States Geological Survey in Washington. He had served with the survey from 1886 to 1925.

ACCORDING to a press dispatch Max von Pidoll and his wife committed suicide simultaneously, but in different localities, on October 29. Dr. von Pidoll, who had recently been appointed professor of mathematics in the University of Innsbruck, had suffered from a chronic illness. He was forty-three years old.

Nature reports the death of Dr. D. Adamson, past president of the Institution of Mechanical Engineers, on October 11, aged sixty-one years; of Dr. H. R. H. Hall, keeper of the Egyptian and Assyrian Antiquities, British Museum, on October 13, aged fifty-seven years; of Professor Paul Wagner, director of the Agricultural Research Station at Darmstadt from