fited and civilization advanced. Grand possibilities lead her votaries on in the hope of still greater achievements than any yet accomplished. The diffusion and advancement of scientific knowledge are the objects of the Association for the Advancement of Science. F. W. PUTNAM.

Permanent Secretary, A. A. A. S.

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*BOLOMETRIC INVESTIGATIONS IN THE INFRA-RED SPECTRUM OF THE SUN.**

WHEN Sir Isaac Newton allowed a beam of light to fall upon a triangular bar of glass, and thus demonstrated the complexity of ordinary light, he undoubtedly rendered science a great service: but when he stopped there, and said that all transparent substances affected light both qualitatively and quantitatively alike, he did it an injury almost as great. The weight of his word deterred investigators and retarded the development of this branch of optics for very many years. At last it was shown that all transparent substances affect light differently. Some bend all the colors considerably out of their course, while scattering or 'dispersing' them but slightly. Others bend, or 'refract,' but slightly, and 'disperse' considerably. In general the violet is 'refracted' most, followed by blue, green, yellow, orange and red, which is refracted least. Similarly, Newton's advocacy of the theory that light is material particles, 'corpuscles,' thrown out from the luminous body, added to the difficulties of gaining a general acceptance of the rival theory, which sees in light only a periodic, or 'wave,' motion, in a hypothetical elastic medium. To-day every scientist accepts the undulatory, or wave, theory of light and is even striving to make it unite the phenomena of light and electricity in one common explanation.

Long after Newton's corpuscles had passed out of science, 'caloric,' or the heat fluid, still maintained its list of respected advocates, and it remained for the first half of this century to relegate 'caloric' to the curiosity shop along with the 'corpuscles.' Then it was that heat was recognized as another manifestation of those periodic disturbances, or waves, in that elastic medium which was then known as the luminiferous ether, and which is now universally referred to as 'the ether.' In 1802 Wollaston, upon repeating Newton's experiment, discovered certain dark bands traversing the colors and apparently separating them. Some ten years later Fraunhofer made these bands the subject of very extensive and careful investigation, observing several hundred and mapping and naming the more important among them. These lines are commonly known now as 'Fraunhofer lines,' and are used as milestones in the spectrum. Thanks to the labors of Wollaston, Fraunhofer, Brewster, Angstrom, Kirchoff, Bunsen and many others in less degree, we know that a chemical element, as sodium, when its vapor is heated sufficiently, will radiate only certain kinds of light; sodium, yellow; thallium, green; lithium, red, and so on. The light from any white-hot solid, when passed through a prism, is dispersed into a spectrum having all the colors and no dark lines, that is, a 'continuous spectrum.' If we put soda in an alcohol flame it will emit yellow light, which, being sent through a prism, will not give a continuous spectrum, but only a band of yellow at that place where the yellow would come in a continuous spectrum. Now, if the light of a white-hot solid, electric arc-light, for example, be caused to pass through the soda flame and then be dispersed into a spectrum, we shall find the latter to be continuous, except for a dark band at exactly that part of the yellow where the soda flame gave a yellow band. The soda vapor in the alcohol flame absorbed out of the white light just

* Part of a popular lecture under the auspices of the New York Academy of Sciences.

that kind of light which it can itself radiate. (Kirchhoff's law.) In the spectrum of sunlight we find a Fraunhofer line at just the same point as the dark line occurs when the white light is passed through the soda vapor. The more exact the measurement the more perfect is the coincidence, hence we are compelled to conclude that the light from the white-hot body of the sun has passed through hot soda vapor before it reached our prism; this must have been in the sun's atmosphere, therefore sodium must exist in the sun. The reasoning is analogous and even more convincing that hydrogen with three lines is there, iron with its many hundred, and so of many other of the elements known to us. Some of the Fraunhofer lines do not correspond to any of our elements, but may be identified at any moment, as, for example, those of the recently discovered argon and helium.

The question was soon raised, whether the energy stopped sharply at the red and violet, or extended into the invisible. So-called fluorescent substances soon found something, 'actinism,' beyond the violet, and the thermometer soon found heat beyond the red, and thus began the campaign into the unknown invisible regions of the 'ultra-violet' and the 'infra-red.'

A word as to the size of these little waves and their rapidity of vibration. They are so small that for their measurement a special unit was adopted. The 'micron' (short) is $\frac{1}{1000}$ of a millimeter, or $\frac{1}{25400}$ of an inch, and is usually represented by the Greek letter mu, μ. A 'wave' whose length, including both hill and valley, is 0, 75μ ($\frac{75}{25400000}$ inch), and which vibrates only about four hundred thousand million times per second, produces the sensation of red in our eyes. If the rate is seven hundred million times per second and the length about 0, 43μ ($\frac{43}{25400000}$ inch) the sensation will be violet. Between these limits the sensations are the various reds, oranges, yellows, greens and blues. Beyond these extremes the vibrations have no visible effects upon our eyes.

Photography in the trained hands of Victor Schumann, of Leipzig, has carried the frontier in the ultra-violet out to a wave length of 0, 12μ, or a distance more than equal to the whole visible specrum from red to violet. Meanwhile the 'bolometer,' with the consummate manipulation of S. P. Langley, has forced the limits of the infra-red to 10, 0μ, with good assurances of waves two or three times as long as that, giving us an infra-red spectrum at least twenty times as long as the entire visible one from violet to red.

Metals on being heated increase their resistance to the passage of an electric current; in this fact lies all the secret of success in infra-red spectrometry. Wheatestone devised a system of electrical connections with battery and galvanometer, which compares resistances just as a lever balance compares weights. (See Fig. 1.) Let us

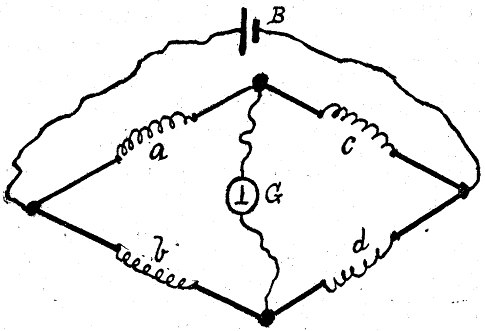

FIG. 1. Diagramatic representation of the connections of a Wheatestone bridge; *a*, *b*, *c*, *d*, are the four resistances; *B* the battery and *G* the galvanometer.

suppose two very thin strips of metal to be so arranged in a Wheatestone balance (or 'bridge' as it is called) (See Fig. 2); when the adjustment is correct no current will run through the galvanometer, and the beam of light reflected from the little mirror attached to the 'needle' remains stationary. If one of the strips be now warmed, ever so slightly, its resistance will be increased, the balance is destroyed, a current of electricity traverses the galvanometer and the beam of light is deflected from its normal position (zero). The de-

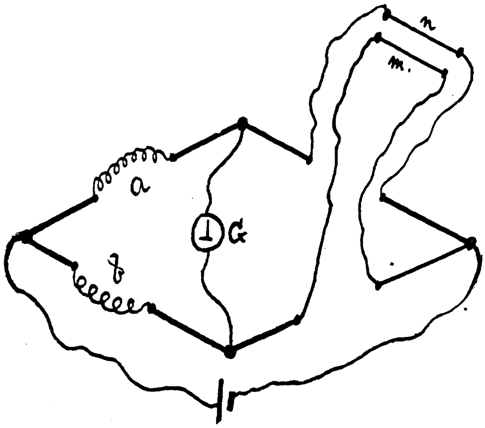

FIG. 2. Diagram of Wheatestone bridge showing how the two resistances *c* and *d* are replaced by the 'side arm' *n* and the 'middle arm' *m* of the bolometer.

flection is a measure of the heating of the strip, and the position of the spot of light upon a scale always tells the thermal condition of the strip. Such a pair of strips, fitted with many devices and special adaptations, constitutes a 'bolometer.' One strip, called the 'central arm,' is exposed to the radiations to be measured, while the other, 'side arm,' is carefully shielded therefrom. The exposed strip of a bolometer for spectrum work is about 8 mm. long, $\frac{1}{20}$ mm. wide, and $\frac{1}{200}$ mm. thick ($\frac{1}{3} \times \frac{1}{500} \times \frac{1}{5000}$ inch) appearing like a fine hair. Of course the galvanometer is the most delicate, and all precautions are taken. Such a system will record a rise in temperature of one of its strips of less than $\frac{1}{1000000}$ of a degree centigrade ($\frac{1}{500000}$ Fh.)

Professor Langley's pioneer work into the infra-red regions of the spectrum was all by visual observations with the bolometer. Let us suppose that some invisible Fraunhofer line is to be located. A large clockwork arranged to rotate a mirror is so adjusted that it reflects a beam of sunlight upon the slit of the spectrometer, which then gives a distinct spectrum, with its lines visible and invisible. The bolometer, mounted upon the arm of the spectrometer, is so set that its central arm coincides with some visible Fraunhofer line, and the circle of the spectrometer is read. This is the starting point. The arm is then turned until the bolometer stands where a line is sought. Again the circle is read. The slit of the spectrometer is then closed and the position of the spot of light at the galvanometer is noted. The slit is opened and the galvanometer read, then the slit is closed and the galvanometer read. The average of the first and third galvanometer readings subtracted from the second gives the deflection due to the radiant energy falling upon the bolometer at that particular point in the invisible infra-red spectrum of the sun. The arm is now moved forward a little, bringing the bolometer into a new part of the spectrum. Again a series of deflections are read and the energy measured. Thus hundreds and thousands of points in the spectrum are determined, and these, when plotted, show the deep valleys where the energy runs low and the hills where it is abundant. In this way Professor Langley and his assistants, with consummate patience and perseverance, felt over the long stretches of the infra-red, mapping a beautiful 'energy curve,' with its many little notches and its four or five huge valleys separated by high peaks.

Some time after Prof. Langley's advent in Washington he organized an astrophysical observatory and in it has prosecuted his investigations by a new method and with renewed enthusiasm. The essential principles of the operation remain the same,

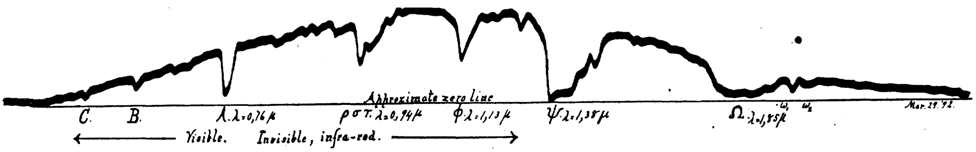

FIG. 3. One of the first bolographs, made in six minutes. A curve where the abscissae depend upon the wave-lengths of the undulations; and each ordinate is the amount of energy of the wave-length represented by the corresponding abscissa. *C*, *B* and *A* are the visible Fraunhofer lines; $\rho\sigma\tau$, Φ, Ψ, Ω, and ω_1 ω_2 are absorption bands in the infra-red. λ stands for wave-length.

only the record is automatic. The spot of light reflected from the mirror of the galvanometer no longer falls upon a scale, but upon a photographic plate which is raised or lowered by a clockwork. The same mechanism drives the tangent screw of the spectrometer, thus slowly swinging the bolometer through the spectrum. Now the operation is as follows: When all the adjustments have been made, the reading of the circle is noted at the starting point. At the signal the slit is opened, and a few seconds later the clockwork is set in motion, swinging the arm and lifting the plate. So long as the bolometer receives the same quantity of energy the spot of light remains stationary and traces a vertical line upon the rising plate. If the bolometer encounters an absorption band it cools off and the spot of light moves to one side, making a break in the trace. If it encounters a warm region the deflection will be in the opposite direction, and so on. The bolometer strip, as it sweeps through the darkness beyond the red, traverses regions varying in their quantities of heat, and continually reports its condition by the deflections of the spot of light, which is recorded in an irregular line upon the plate until at the signal everything stops, and in ten minutes an energy curve has been traced, better in nearly every respect than Prof. Langley's first one, which represents thousands of tedious observations. (See Fig. 3.) By this method, in a few hours of good work, curves are obtained which show hundreds of lines where dozens were intimated before. (See Figs. 4 and 5.) One must have seen it to appreciate the fascination of watching that simple spot of light and seeing in one's thoughts that little strip climbing up the heights of energy mountains only to plunge

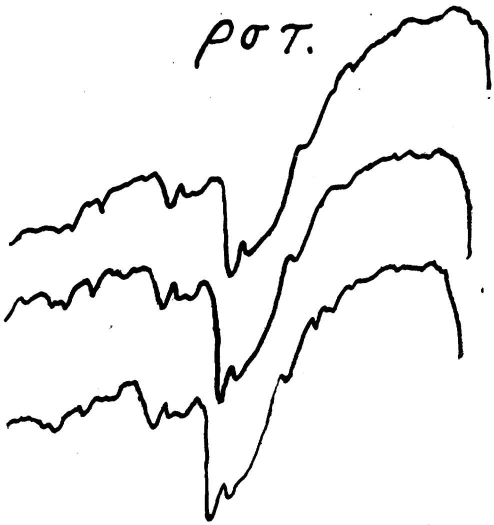

FIG. 4. Three bolographs of the infra-red group $\rho\sigma\tau$ showing how well different records agree, even in detail.

into a cold abyss upon the other side, absolutely unerring, overlooking no trifling hillock, overestimating no lofty peak.

When desired, such energy curves can be converted into 'line-spectra,' similar to the photographs of the visible Fraunhofer lines. Such a line-spectrum, combined with Schumann's photographs of the ultra-violet and Rowland's of the visible spectrum, upon Rowland's scale, would give us a radiant energy spectrum about six hundred feet long.

Of what use is all this? Could Faraday foresee that Morse would invent the telegraph or Bell the telephone? Could Helmholtz or König foresee the phonograph? Fortunately we live at a time when any addition to the world's knowledge of nature's truths is sufficient justification for any investigation however laborious.

The bolometer has already taught us that the firefly is a dozen times more economical as a light producer than our best electric

FIG. 5. A bolograph of the sodium double yellow line indicating the nickel line between them. This will show the extreme delicacy of this method of feeling and recording absorption lines.

lights and a hundred times better than our gas. It has taught us that our atmosphere acts like a valve, transmitting in almost undiminished strength the short quick waves of energy radiated to us from the sun, but refusing absolutely to return the long slow waves in which the earth tries to radiate the energy back into space. Without this atmosphere we should all have been frozen long ago.

We now know of electric waves which behave in every respect similarly to those of light, but which are many times longer and slower. Almost every month brings the announcement of shorter and faster electric waves, while Prof. Langley and his fellow laborers are continually detecting longer and slower light waves. Thus the boundaries of our knowledge are forced forward, and the unexplored strip becomes ever narrower. Light is as it were the snowy cap of a mountain. One explorer pushes downward from the light top into the dark regions lying below, while another from the broad and fertile valley of electricity struggles upward into the unknown. Are the two upon the same mountain? Will they ever meet? We hope so, we believe so, but until they have clasped hands we are not satisfied. Other workers may be found to be upon the same ether mountain, gravitation and other mysteries may there find a solution. What is above our mountain, unencumbered ether? thought? life?

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VERTEBRATE PALEONTOLOGY IN THE AMERICAN MUSEUM.

THE American Museum of Natural History has recently acquired the collection of fossil mammals, made by Professor Cope between 1872 and 1895. The collection represents eleven geological horizons, including specimens from the Jurassic, Laramie (Cretaceous), Puerco, Wasatch, Wind River, Bridger, Washakie, White River, John Day, Loup Fork and Pleistocene. The collections from the John Day and Wasatch of New Mexico and Wyoming are exceptionally perfect, and that from the Puerco, together with the collection already in the Museum procured by the expedition of 1892, is unique. Four hundred and seventy species are represented, of which four hundred and two are types. The collection is representative of all of Professor Cope's researches upon the mammalia, with the exception of the greater portion of his work upon the Wheeler Survey, the types of which are contained in the Smithsonian Institution of Washington, and more recently of his work upon the Canadian and Texas Surveys. The most complete speci-