The demonstration of a change in sequence of identical loci that is here reported makes the identification of parallel mutations in species that cannot be crossed even more difficult than it has previously seemed; for identity of sequence in a group of identical loci now appears not to be necessarily expected.

0.0	dachs
14.2	scarlet
39.0	deltoid
76.5	peach

FIGURE 1

0.0	roughoid
41.5	scarlet
44.5	peach
63.5	delta
101.0	minute-23

FIGURE 2

[1] Contribution from the Carnegie Institution of Washington.

[2] Sturtevant, A. H., *Genetics*, **6**, 1921 (63, 179).

[3] Discovered by Prof. T. H. Morgan.

[4] Discovered by Dr. C. B. Bridges.

[5] This map is based on the more extensive one published by Bridges in these PROCEEDINGS.

[6] Bridges, C. B., *J. Gen. Physiol.*, **1**, 1919 (645).

[7] Weinstein, A., these PROCEEDINGS, **6**, 1921 (625).

[8] It is, of course, possible to invert this interpretation by supposing the simulans situation to be the original one.

[9] Muller, H. J., *Amer. Nat.*, **50**, 1916 (103, 284, 350, 421), and Sturtevant, A. H., *Carnegie Inst. Wash. Publ.*, No. 278, 1919 (305).

[10] Sturtevant, A. H., these PROCEEDINGS, **3**, 1917 (555), and *Carnegie Inst. Wash. Publ.*, No. 278, 1919 (305).

A REMEASUREMENT OF THE RADIATION CONSTANT, h, BY MEANS OF X-RAYS

BY WILLIAM DUANE, H. H. PALMER AND CHI-SUN YEH

JEFFERSON PHYSICAL LABORATORY, HARVARD UNIVERSITY

Communicated July 6, 1921

Since the discovery of the fact[1] that the continuous X-ray spectrum has a short wave-length limit, which obeys the quantum law, a number of experimentors have used this phenomenon to determine the value of h.[2] In its application to X-rays the quantum law may be expressed by the equation

$$Ve = h\nu, \qquad (1)$$

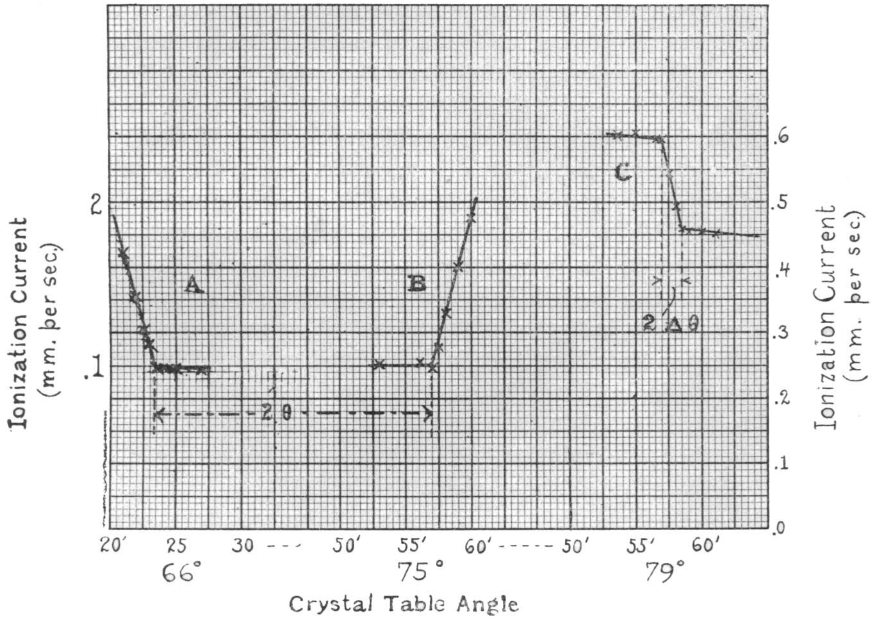
where V represents the maximum difference of potential in the X-ray tube through which the electrons fall, e, the charge carried by each electron, ν, the frequency of vibration corresponding to the short wave-length limit of the spectrum, and h, Planck's action constant. Evidently a measurement of V and ν gives us the ratio of h to e, and from this we get h, if we suppose e to be given by other experiments. Blake and Duane[3] made the most accurate measurement of h in our laboratory. Using Millikan's value of $e = 4.774 \times 10^{-10}$ they obtained the value $h = 6.555 \times 10^{-27}$.

The object of the research reported in this note is to increase the accuracy of the measurement of h. We use a new and somewhat improved spectrometer and a new calcite crystal. The X-ray tube contains a tungsten target and a Coolidge cathode. A side arm attached to the tube extends out toward the spectrometer and carries at its outer end a thin mica window. The increased intensity of the X-rays coming through this window enables us to use a narrower spectrometer slit, which reduces the correction that must be made for the slit's width.

As in the previous researches the high tension storage battery supplies the current through the X-ray tube. In the present research we have greatly increased the accuracy of the measurement of the difference of potential applied to the tube. Whereas in the previous researches this difference of potential was compared with the electromotive force of a standard cell through the calibration of several intermediate instruments (an electrostatic voltmeter, an ammeter, and a potentiometer), we now compare the difference of potential directly with the electromotive force of a standard cell by means of the simple potentiometer method. In this way we eliminate the errors in the calibrations of the various instruments. The main circuit in the simple potentiometer consists of a large number of coils of manganin wire having a total resistance of over six million ohms. We use the same precautions in insulating the various circuits as one employs in making measurements of ionization currents. The ratio of the resistances of two sections of the main circuit gives us directly the ratio of the difference of potential to the electromotive force of the standard cell. As the ratio of two resistances can be measured with extreme accuracy, we think that we know the difference of potential applied to our X-ray tube with about the accuracy with which the electromotive force of the standard cell has been determined. We use two unsaturated Weston standard cells, each of which has been tested at the Bureau of Standards, and we compare them with each other from time to time. The certificates from the Bureau give the electromotive forces of the cells to within one part in ten thousand.

The actual drop in potential in an X-ray tube through which the electrons fall differs from the drop in potential measured by the potentiometer by a small amount due to the Volta effect, the current that heats the coil of wire in the Coolidge cathode and the high temperature of the wire. In our experiments the circuits are so connected and the voltage applied to the tube is so high that we may neglect the corrections due to these effects.

In making a measurement of h, one experimenter observes the galvanometer attached to the potentiometer, and by varying a resistance in series with the X-ray tube keeps the difference of potential applied to it constant during the experiment. A second observer measures the current in the spectrometer's ionization chamber. A series of readings is taken on the two sides of the spectrometer's zero near the points at which the continuous X-ray spectrum vanishes. Curves A and B in the figure represent the ionization currents as functions of the angles that fix the positions of the reflecting crystal in one of the experiments. The horizontal portions of the curves correspond to the currents due to natural leak and to stray radiation.



The inclined portions represent the increase in these currents due to the continuous X-ray spectrum. The readings corresponding to the short wave-length limit of the spectrum can be determined to within a few seconds of arc. As indicated in the figure, the difference between these readings on the two sides of the zero gives us twice the glancing angle θ, which must be substituted in the equation

$$\lambda = 2d \sin \theta = 6.056 \times \sin \theta \times 10^{-8}\text{cm}. \quad (2)$$

in order to calculate the shortest wave-length λ, in the continuous X-ray spectrum.

A small correction has to be added to the observed value of θ, due to the fact that the source of rays and the slit of the spectrometer are not mathematical lines. The correction for the breadths of the source and slit we determine in two ways. Firstly, we estimate the apparent breadth of the focal spot as seen from the spectrometer's slit, and then measure the width of the slit by the method described on p. 630 of the paper by Blake and Duane referred to above.[3] Secondly, we measure the breadth of the drop in the ionization curve due to the K critical ionization of bromine. The ionization chamber containes ethylbromide. Curve C in the figure represents this drop in the curve in one of the experiments. The breadth of this drop corresponds within the limits of error of the measurements to the correction to be added to the double angle 2θ, as determined by the first method. The correction is small. It amounts to less than one part in three hundred.

Incidentally, the measurements we have made of the critical ionization of bromine gives a very accurate measurement of its critical ionization wave-length. As an average we obtained the value

$$\lambda = (.9180 \pm .0002) \times 10^{-8} \text{ cm.},$$

assuming that the grating constant of calcite is 6.056×10^{-8}cm.

We tried to obtain an estimate of the correction for the breadth of the source and the slit by measuring the breadth of a peak on the ionization curve corresponding to a line in the characteristic emission spectrum of the tungsten target. In every case examined, however, the breadth of the peak appeared to be slightly broader than what the measured breadth of the source and slit indicated it should be. This means that the corresponding emission lines have certain finite, intrinsic breadths of their own. If the K critical ionization of bromine has such an intrinsic breadth it is too small to be detected in these experiments.

Since from the wave equation,

$$\lambda \times \nu = c = 2.9986 \times 10^{10}$$

where c is the velocity of light, we can calculate immediately the maximum frequency ν in the continuous spectrum. This, together with the difference of potential, V, substituted in equation 1, gives us the ratio of h to e.

The data obtained in four complete measurements of h appear in table 1. Column 2 contains the uncorrected values of θ, column 3 the correc-

TABLE 1

GLANCING ANGLES AND RADIATION CONSTANT

DATE	θ(UNCORRECTED)	$\Delta\theta$	θ(CORRECTED)	$V \sin\theta$	h
March 15	4°-46′-43″	47″	4°-47′-30″	2039.2	6.5539×10^{-27}
March 21	4°-46′-53″	43″	4°-47′-36″	2039.9	6.5561 "
March 30	4°-46′-53″	51″	4°-47′-44″	2041.0	6.5594 "
April 5	4°-46′-48″	45″	4°-47′-33″	2039.6	6.5552 "
			Mean	2040.0	6.5562×10^{-27}

tion for the breadths of the source and of the slit, and column 4, the corrected values of θ. Column 5 contains the values of the product $V \sin\theta$ (which is what we really measure in our experiments). This product depends to a slight extent upon the temperature. The temperature in these experiments is about 20° Centigrade. The value of V as measured by the potentiometer is 24,413 volts in each case. We estimate that the error of precision in the product $V \sin \theta$ amounts to about one part in two thousand.

Column 6 contains the values of h calculated from the values of $V \sin \theta$. Since several constants occur in these calculations (the velocity of light, the grating constant of calcite and the charge on the electron), the values of h are not quite as accurate as those of $V \sin \theta$. We estimate the probable error in h to be about fifteen parts in ten thousand. This gives us an average

$$h = (6.556 \pm .009) \times 10^{-27}.$$

This value of h agrees with that previously published by Blake and Duane.[3] It is, however, a fraction of one per cent larger than the value recently obtained by E. Wagner in a careful series of measurements.

In the experiments described above the X-rays left the target in a direction at right angles to the line of motion of the cathode particles. An interesting question has been raised recently as to whether the limit of the continuous spectrum would be altered if the rays came off at some other angle.[4] To test this point with the accurate method of measuring the voltage which we now have, we made a series of experiments with an ordinary Coolidge tube (tungsten target) placed so that the X-rays that passed through the spectrometer's slit left the target at an acute angle of about 45° to the direction of the cathode stream. The results of this series of measurements appear in table 2. As in the previous experiments the voltage applied to the tube amounted to 24,413 volts. The X-ray tube had no thin mica window, so that the accuracy appears to be somewhat less than in the previous series of measurements. The value of $V \sin \theta$, however, does not differ from that for rays at right

TABLE 2

GLANCING ANGLES AND RADIATION CONSTANT

DATE	θ(UNCORRECTED)	$\Delta\theta$	θ(CORRECTED)	$V \sin \theta$	$h \times 10^{-27}$
April 6	4°-46′-35″	1′	4°-47′-35″	2039.8	6.556
April 6	4°-46′-33″	1′	4°-47′-33″	2039.6	6.555
April 12	4°-46′-53″	48″	4°-47′-41″	2040.7	6.558
April 27	4°-46′-43″	47″	4°-47′-30″	2039.3	6.554
				2039.9	6.556

angles to the cathode stream. There does not appear to be a Doppler effect for the short wave-length limit of the spectrum that amounts to as much as one part in two thousand. This agrees with Wagner's results.[4]

A very much more detailed report of this research is being published in one of the Physical Journals.

[1] Duane and Hunt, *Physic. Rev., Ithaca*, Aug., 1915, p. 166.

[2] See a report in the *Jahrbuch der Radioahctivität*, etc., for 1919 by E. Wagner, and

also a report on "Data Relating to X-Ray Spectra" by William Duane, published by the NATIONAL RESEARCH COUNCIL.

[3] Blake and Duane, *Physic. Rev.*, Dec., 1917, p. 624.

[4] See E. Wagner, *Jahrbuch der Radioahctivität*, 1919, also *Physik. Zeit.*, Nov., 1920, p. 621; and C. Zecker, *Ann. Physik. Leipsig*, Sept., 1920, p. 28, also a note by D. L. Webster, presented to the American Physical Society at the same meeting at which the authors presented a note on this research, April, 1921.

THE U-TUBE ABSOLUTE ELECTROMETER

By CARL BARUS

BROWN UNIVERSITY

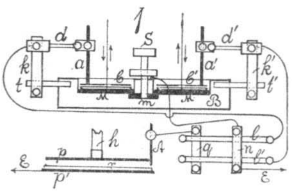
Communicated May 25, 1921

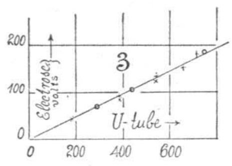
1. *Electrical Condenser.*—Adjusting the wide shank of the shallow U-tube heretofore described (these PROCEEDINGS, **7,** 1921, p. 71) with the top plates removed, so as to admit a metallic disc above the earthed mercury surface and parallel to it, the device becomes an absolute electrometer. The disc is perforated at the middle so that the component rays of the interferometer may reach the mercury. This instrument is chiefly useful in measuring electrostatic potentials. If p is the electric-pressure below the disc charged at potential difference V and h is the head of mercury resulting

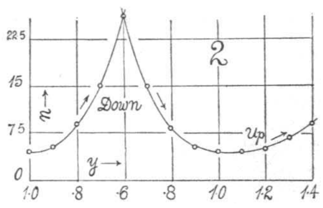
$$V = d\sqrt{8\pi p} = d\sqrt{8\pi h\rho g} = d\sqrt{4\pi\lambda\rho g . n}$$

where d is the distance between disc and mercury, ρ the density of mercury and λ the wave-length of light when n fringes correspond to V. Hence if $d = 1$ millimeter, $V = .315\sqrt{n}$ els. units; or $= 95\sqrt{n}$ volts.

2. *Improved Apparatus.*—The electrometer eventually took the form shown in figure 1 which gives the apparatus in connection with the electrophorus







and a commutating key similar to Mascart's. To put the mercury M to earth, a steel screw, S, which also carries a flat clamp for fastening one end of the earthed wire, has been inserted. This screw, S, has the further important purpose of damping the oscillations of the mercury M or M', by adjustably closing the channel m. The deflections can thus be made quite dead beat, which is an advantage. To level the electrodes C, C' (using a small spirit level placed on them) each has connecting rod d, which carries a clamp at one end, allowing the rod a, a' to slide up and down, rotate