

from the hot body to the surrounding enclosure." Now I was wrong in objecting to this particular passage, for just here Richardson is speaking of an insulated piece of metal which is imagined to give off electrons that do work as a gas on a moving piston; and for such a 'virtual' operation his statement is doubtless true. But in his *experiments* he is really taking off a stream of electrons in the gas state from the metal, and an equal stream is constantly entering the metal by conduction, yet he assumes that the same  $\Phi$  which occurs in the equation above quoted, for his case of virtual emission from an insulated body, holds as the heat of emission for his actual case.

It was this actual case, of electric flow, that I had in mind when I offered my criticism that his equation for  $dS$  fails when not only heat but substance also, that of the incoming electrons, is added to the system during the operation under consideration. I believe that this objection holds.

Bridgman, missing my point through my lack of precision in stating it, studied Richardson's argument again and presently made for himself the same discovery that I had made, so that he and I are now in agreement regarding the inaccuracy of Richardson's reasoning. He finds, moreover, that, when this inaccuracy is corrected, Richardson's line of argument leads to precisely the same result as Kelvin's.

Accordingly Bridgman now writes  $P'$  instead of  $P$  in the equation in question, meaning by  $P'$  the total reversible heat effect that accompanies a virtual movement of charge from one plate to another of a condenser made of different metals, though he may not subscribe entirely to my theory as to the action of ionization and re-association within the metals.

I hope that Professor Bridgman's paper, dealing with thermo-electricity in a broad way, will be published before long.

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### ON THE X-RAY ABSORPTION WAVE-LENGTHS OF LEAD ISOTOPES

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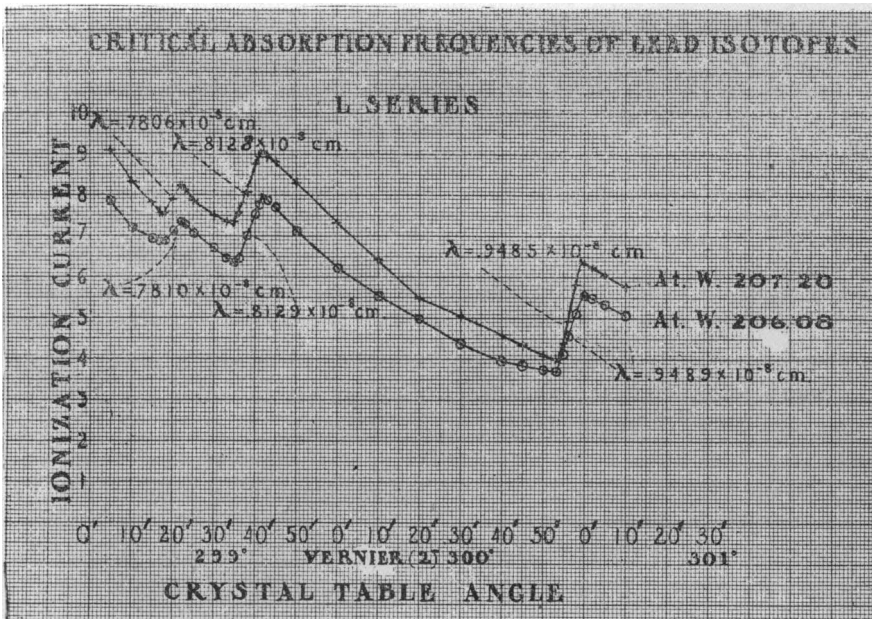
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Researches on the transformations of radioactive substances have led to the conclusion that chemical elements exist which have the same atomic number but different atomic weights. Such chemical elements have been called isotopes. In the reactions of ordinary chemical analysis isotopes behave in identically the same manner. It has not been found possible to separate isotopes from each other by means of purely chemical processes; although it seems probable that, since the atomic weights of isotopes differ from each other, they will act somewhat differently in those phenomena in which the mass of the atom enters as a factor. The ordinary line spectra of

chemical isotopes, also appear to be identical to a very high degree of precision, and recently Siegbahn and Stenström found no difference between their emission spectra in what is called the L series of X-rays.

The object of the research reported in this note has been to investigate the X-ray absorption spectra of chemical isotopes. In general each chemical element, except perhaps those of low atomic numbers, has several critical absorption frequencies, one connected with its K series and three connected with its L series of X-rays. These critical absorption frequencies mark points in the X-ray spectrum where sharp changes in the absorption of X-rays by the chemical element occur. The chemical element absorbs X-rays of higher frequency than the critical frequency to a much greater extent than it does X-rays of lower frequency.



In measuring the critical absorption frequencies of lead isotopes we have used the X-ray spectrometer described in the *Physical Review* for December 1917, page 624. A calcite crystal reflected the X-rays whose wave-length is given by the equation

$$\lambda = 2 a \sin \theta = 6.056 \sin \theta \times 10^{-8} \text{ cm.}$$

(where  $\theta$  is the grazing angle of incidence) into an ionization chamber. The ionization method of detecting the reflected beam of X-rays is far superior to the photographic method, both because, if properly used, it requires no correction for the penetration of the X-rays into the crystal, and also because it gives an estimate of the magnitude of the absorption.

The absorbing screen of lead was placed between the X-ray tube and the spectrometer. Professor Richards' laboratory kindly furnished us with the specimens of lead salts. Professor Richards has made accurate measurements of the atomic weights of lead isotopes, and the values he obtained for the two specimens we used were 207.20 for the ordinary lead and 206.08 for the radioactive lead. These differ from each other by more than  $\frac{1}{2}\%$ .

In our experiments the X-rays came from a molybdenum target tube of the Coolidge type, and a constant difference of potential amounting to about 36,000 volts drove a current of 2 milliamperes through it.

The curves in the figure represent the ionization currents as functions of the readings of one of the verniers attached to the crystal table.

The three sharp drops in each curve correspond to the three critical absorption wave-lengths belonging to the L series of X-rays of each specimen of lead respectively. To get the grazing angles of incidence to substitute in the above formula for the wave-length we measured from the centres of the drops to the zero,  $291^{\circ} 55' 40''$ , the value of which has been corrected for eccentricity.

The values of the wave-lengths, etc., have been collected together in the following table.

ABSORBING SCREEN	ATOMIC WEIGHT	$\lambda \times 10^8$ CM.	$\lambda \times 10^8$ CM.	$\lambda \times 10^8$ CM.
Ordinary lead .....	207.20	0.9485	0.8128	07.806
Radioactive lead .....	206.08	0.9489	0.8129	0.7810

The grazing angles of incidence can be estimated to within about  $30''$  of arc, which means that the wave-lengths are correct to within about  $0.1\%$ . Corresponding wave-lengths for the two specimens in the above table do not differ from each other by as much as  $0.1\%$ , and, therefore, the critical absorption wave-lengths of the isotopes of lead are identical to within the limits of error of the experiments.

The magnitude of the characteristic absorption can be estimated from the drops in the curve. These depend, of course, upon the thickness of the absorbing layer, and its measurement is very much less accurate than that of the wave-length. It appears, however, that the relative change of absorption at the three critical wave-lengths is about the same for each isotope of lead.