

THE L SPECTRA OF IRON ABOVE THE CURIE POINT

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INTRODUCTION.

As seen from Thoraeus' ¹ Moseley diagrams of the M levels of the elements of the atomic numbers 24 to 35, a change of slope for each level occurs at copper (29). There is a decided bend in the curve for the $M_{IV, V}$ level. The L levels are more strikingly anomalous. The wide separation of the levels L_{II} and L_{III} which may be obtained from the difference in the energy of the K_{α_1} and K_{α_2} lines and by soft x-ray work from the difference $L_{\beta_1} - L_{\alpha_2}$, as well as, $L_{\alpha_2} - L_{\gamma}$

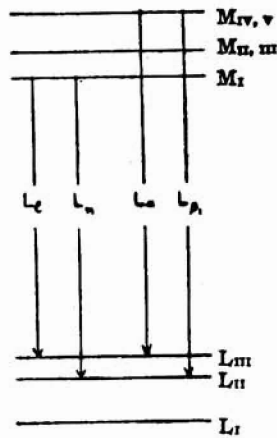


FIGURE 1.
X-ray energy level diagram.

as shown in the energy level diagram, figure 1 is surprising: If the difference $L_{II} - L_{III}$ be plotted against atomic number, as shown in figure 2, the elements iron (26), cobalt (27) and nickel (28) form a "hump" on an otherwise smooth curve. Also, as shown by Thomas ² from the critical potentials of the L series of iron, cobalt, nickel and copper that when L_I , L_{III} , L_{α_1} , L_{α_2} are plotted against atomic

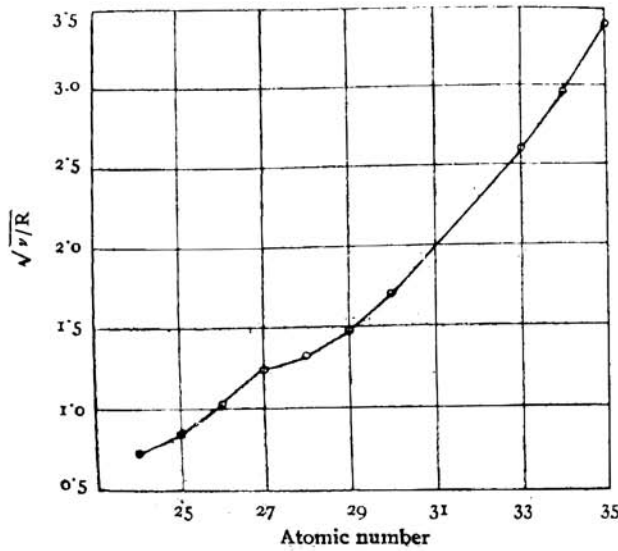


FIGURE 2.

Moseley diagram of $L_{III}-L_{III}$ of the elements 24-35.
(Data from Thoriaeus table VI).

number, the Moseley curves show a change of slope between nickel and copper. These sudden changes in the structure within the M and L spectra are thought by Thoriaeus and others to be connected with the magnetic properties of the elements of the iron group, probably due to some changes of the electronic arrangements in the energy level $M_{IV, v}$. Since $M_{IV, v}$ shell is incomplete for elements below copper, the building up of the level may have a considerable effect on its Moseley diagram. The other M levels and also L levels are likely to be affected by the addition of $M_{IV, v}$ electrons. This shell is believed to be responsible for ferromagnetism.

In order to determine whether the M levels and the abnormally separated L_{II} and L_{III} levels are dependent upon the ferromagnetic conditions of the elements, Chalklin³ investigated the L spectra of iron, cobalt, nickel and copper with a plane grating vacuum spectrograph, and found that the values of the energy levels of the three ferromagnetic elements at temperatures above the Curie point as well as at normal temperatures are independent of the magnetic state of the elements:

Sometime ago, Richard Hamer and the writer obtained the L spectra of iron by the method of critical potentials, when the element was at 825°C . This temperature is considerably above the Curie point of 774°C and if the L and M levels were dependent upon the ferromagnetic condition of the element, our results

would differ widely from those obtained by a similar method and with anti-cathodes below the Curie point as used by Thomas⁵ and others. It has been therefore thought that it would be of interest to describe these results fully here and compare them with those of Thomas for iron. In case of close agreement they should give an independent check on Chalklin's conclusion.

DESCRIPTION OF APPARATUS.

The apparatus (figure 3) consisted of a quartz tube T, $17/16$ inches in diameter, with $1/8$ inch walls and 34 inches long. It enclosed two metal electrodes consisting of a central rod R, $5/16$ inch in diameter and 39 inches long, and a concentric cylindrical tube t, $7/8$ inch in diameter, with $1/8$ inch walls and a length of 6 inches. The quartz tube was carefully sealed into a glass head, H, by means of a hard grade DeKhotinsky cement and the joint was kept cool by water circulation. The glass head consisted of a tube with three out-lets; one to the vacuum system, one to a ground glass joint with a tungsten seal, which permitted electrical connections to be made to the suspended rod, and one which allowed connection, by means of the thin rod R' to the metal tube, t. The central rod was connected to the tungsten lead wire by means of a collar C, and could be raised or lowered to meet requirements. The electrodes, the rod as anti-cathode and the metal tube as cathode, were very carefully centralized and precautions against short circuiting were taken.

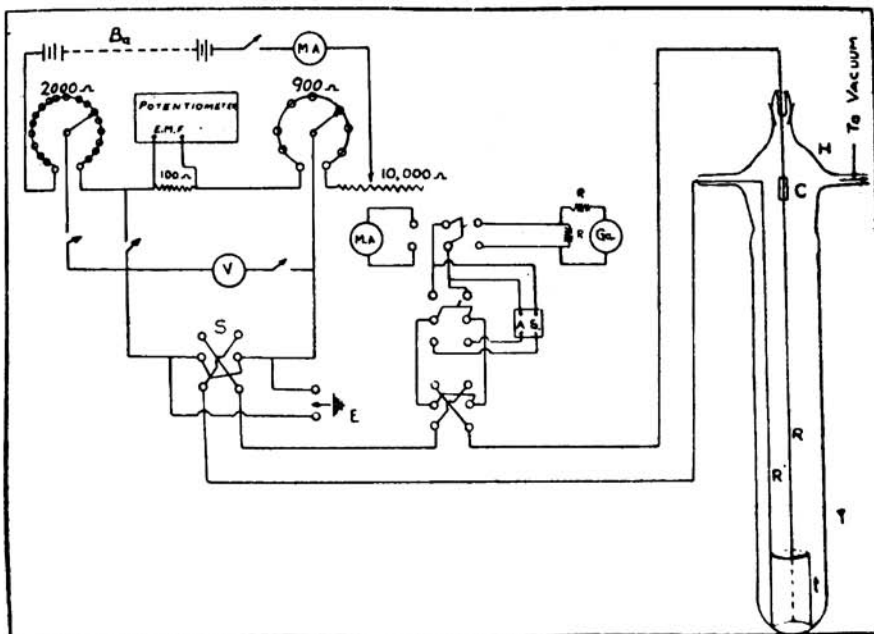


FIGURE 3.

Schematic diagram of the measuring circuit and section of the quartz tube, showing arrangement of metal electrodes.

The vacuum was obtained by means of a mercury diffusion pump backed by a hyvac oil pump. Between the mercury pump and the quartz tube were a liquid air trap and an electric discharge tube, and between the oil pump and the mercury pump were an air drying system and a manometer. The liquid air trap rendered the concentration of any vapor inappreciable. The electric discharge tube was used to estimate the degree of evacuation. The pressure was estimated to be 10^{-6} mm. of mercury before the readings were taken. Whenever it was necessary to let air in the vacuum system it was passed through the air drying system.

As the electrodes were connected to the double throw reversing switch it was possible to reverse the polarity easily. It was also arranged to earth either one of them, which eliminated the possibilities of electrostatic disturbances from the outside.

A potential difference of a desired value between the anti-cathode and the cathode was supplied by storage batteries and was adjusted by a potentiometer method. It was so arranged that nine or ten equal steps could be taken within any desired range of voltage, such as, 0-1, 1-10, 10-20, and so on. The current in the potentiometer system was read in the beginning and checked at the end of each series of ten equal steps.

The current determinations were made with a sensitive suspended coil type galvanometer, arranged with resistance in parallel and in series. These resistances could be so arranged as to give any desired current sensitivity. This was usually arranged so that the maximum current would give a full scale reading. Readings were also taken with a standard Jewell Milliammeter (range 0 to 3 milliamperes) on which the current could be estimated to 0.001 milliampere.

The tube was heated externally by a nichrome wire electric furnace. To insure a constant temperature a steady current was maintained and read with an ammeter. The temperature was determined by means of an optical pyrometer.

EXPERIMENTAL PROCEDURE.

For each set of observations the tube was baked at a temperature of 800°C to 850°C for several hours. At the conclusion of this baking out process, while at red heat, the electrodes were bombarded with electrons and thus practically freed from the occluded gases. Then the current potential curves for the desired range of voltage were obtained.

Changes in potential were made in practically equal or alternately large or small steps and the corresponding changes in the thermionic current were read. The potentiometer arrangement permitted either 19 large equal steps, or 10 large equal steps and ten smaller equal steps, each being equal to one-tenth of the larger. This enabled observations to be taken for plotting the main total current potential curves, when one used the larger steps

only. The use of the smaller steps enabled one to determine the change in the current for a small differential potential at intervals of a larger step. The procedure gave data for curves which indicated quite definitely the changes of slope as the potential difference was changed up or down. It was learned by experiment that these actually observed differentials gave results in good agreement with those computed from the larger steps. This scheme was devised for the express purpose of settling any doubts as to the reality of changes of slope or breaks in the main total current potential curves which the latter indicated as taking place at the critical potentials.

As expected it was found that better results could be obtained with rod positive and the metal tube negative. It was possible to get sufficient electrons from the tube when it was heated to a temperature which should have caused little evaporation of the metal. However, after each set of readings, which usually required that the rod and tube be kept heated ten to twelve hours, a slight decrease in the sharpness of breaks without a change in the positions was noticed. This effect was found to be due to a slight deposit of evaporated metal and when the rod was freshly polished, once more the original sharp breaks in the curves were obtained.

RESULTS.

The critical potentials of iron was investigated up to 132 volts. Typical current potential curves are shown in figures 4 (a) and 4 (b). The values of voltage

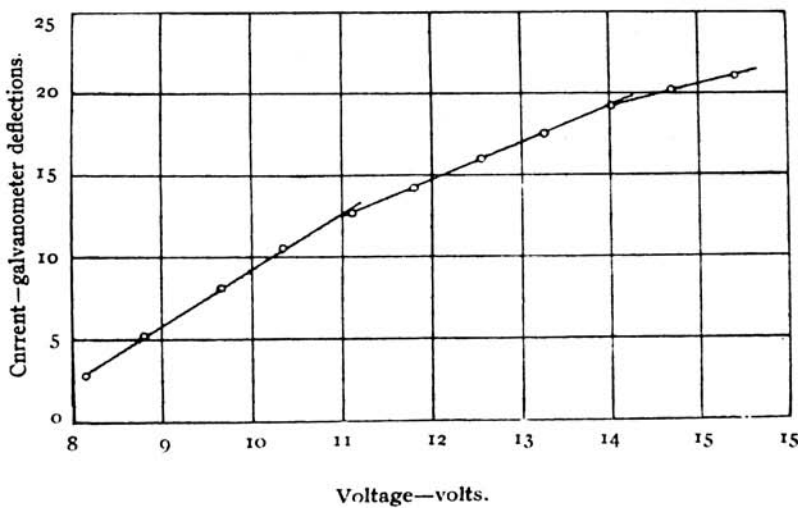


FIGURE 4 (a).

Critical potentials of iron in the range 8 to 10 volts.

and thermionic current were carefully plotted, using voltage as abscissa and galvanometer deflections or millimeter readings as ordinates. All curves of various sets of observations were then examined for marked changes of slope and for breaks, and the values of the potentials corresponding to the points of maximum change of inflection in each curve were then classified and tabulated, placing all breaks, that seem to correspond most closely together in the same column. These values were then averaged and considered to be the experimentally determined critical potentials.

In the first column of table I are given our values of the critical potentials of iron above the Curie point and in the second column are those of Thomas for the same element below the Curie point.

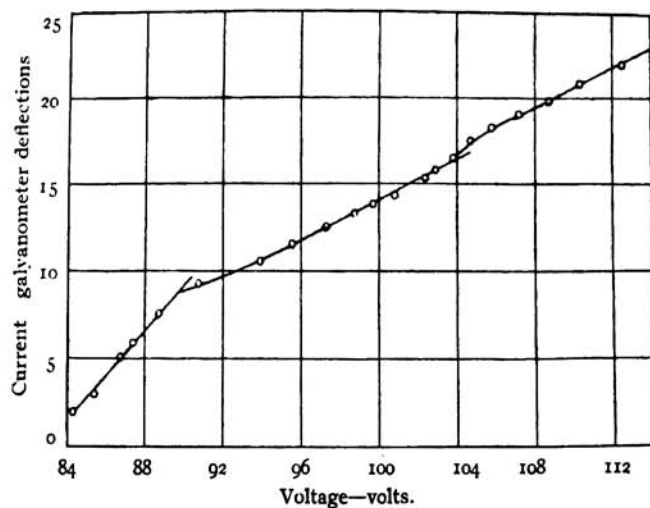


FIGURE 4 (b).

Critical potentials of iron in the range 84 to 110 volts.

TABLE I.

Critical Potentials for Iron above and below the Curie Point.

Hamer and Sidhu. Volts.	Thomas. Volts.
7'15	7'3
11'2	11'1
14'1	14'1
16'3	16'5
19'4	19'4

TABLE I (contd.).

Critical Potentials for Iron above and below the Curie Point.

Hamer and Sidhu. Volts.	Thomas. Volts.
24.5	24.3
29.0	28.8
33.9	34.3
38.8	37.5
42.1	41.2
45.7	---
48.4	48.0
51.4	51.3
54.8	54.6
61.6	62.0
---	67.6
72.7	---
---	75.3
---	82.7
89.6	---
103.1	94.8
---	103.5
111.6	112.2
125.8	125.7

At these potentials inelastic collisions occur between the bombarding electrons and the atoms of the element and characteristic radiations of the extremely ultra-violet and soft x-ray type, involving M and L energy levels, are emitted.

DISCUSSION.

In view of a large number of critical potentials in the range of voltage reported here, the agreement in table I is apparently good. Our 72.7 and 89.6 are possibly average effects corresponding to his 67.6 and 75.5 and 82.7 and 94.8 respectively. Except 45.7, which he did not observe, the rest check within the experimental error.

Both investigations were made with unoxidized and un-contaminated anti-cathodes of iron, below the Curie point by Thomas and above the Curie point by ourselves. Great pains were taken to make measurements in very small voltage intervals to determine definitely, if critical potentials really existed in the above region, and their values ; and also to decide if the breaks or changes of slope in the main curve were really associated with these critical potentials.

We find like Compton and Thomas,⁵ Richardson and Chalklin,⁶ Horton et al.⁷ and others, that the breaks or changes of slope in the main curves are really associated with these critical potentials, which are actually characteristic of the metal target and not accidental. The critical potentials ascribed to the L series especially, as shown by Thomas,² fit very well in the Moseley diagram and are definitely associated with x-ray terms of the series.

It is quite apparent from the close agreement in table I, that critical potentials involving L and M energy levels of the atoms of iron are independent of the magnetic state of the element. Hence the anomalies of L and M level diagrams do not appear to be, as concluded by Chalklin, the result of the magnetic phenomena.

I wish to express my sincere thanks to Dr. Richard Hamer, at whose suggestion this work was undertaken, for his encouragement and ever ready assistance during the course of the investigation. I am grateful for having had the opportunity to discuss this paper with Dr. P. H. Dowling and Professor A. G. Worthing.

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