## Auger Effect and Forbidden Transitions

It is well known that after an atom has been ionised, for example in its $K$ shell, the ensuing reorganisation of the extra-nuclear electronic structure is not by any means invariably accompanied by the emission of $K$-radiation. Quite frequently we have instead a 'radiationless' change of the type first completely specified by Rosseland, which results in the expulsion of a 'photo-electron of the second kind' and in leaving the atom doubly ionised—until further reorganisation occurs—in its X-ray levels. These photo-electrons of the second kind were observed by M. de Broglie, but the manner in which they originate was first clearly established by Auger's beautiful work with the Wilson cloud chamber, and it is convenient and not inappropriate to refer to them as Auger electrons.

In a recent very interesting paper[1], Mr. E. H. S. Burhop has calculated, by the methods of quantum mechanics, the relative probabilities of emission of different types of Auger electrons—that is, corresponding to different types of radiationless switches—from atoms initially ionised in the $K$ shell. The Auger electrons resulting from interactions between the $L$ shells fall into six sets, which may be classified thus:

$$\begin{array}{ll} (a)\ L_{\mathrm{I}}, L_{\mathrm{I}} \rightarrow K,\infty & (d)\ L_{\mathrm{II}}, L_{\mathrm{II}} \rightarrow K,\infty \\ (b)\ L_{\mathrm{I}}, L_{\mathrm{II}}, \rightarrow K,\infty & (e)\ L_{\mathrm{II}}, L_{\mathrm{III}} \rightarrow K,\infty \\ (c)\ L_{\mathrm{I}}, L_{\mathrm{III}} \rightarrow K,\infty & (f)\ L_{\mathrm{III}}, L_{\mathrm{III}} \rightarrow K,\infty, \end{array}$$

the first two symbols indicating the electrons taking part in the disturbance, and the last two their immediate destinations—$\infty$ being an obviously convenient symbol for 'outside the atom'.

Of the six sets, those in $(a)$ will have the lowest energy; $(b)$ and $(c)$ will have approximately equal energies, appreciably greater than $(a)$, and a similar thing is true of the fastest sets, $(d)$, $(e)$ and $(f)$. An instrument of moderate resolving power would therefore (at least for light and moderately light atoms) record these six sets of Auger electrons as three groups, namely, I, set $(a)$; II, sets $(b)$ and $(c)$; III, sets $(d)$, $(e)$ and $(f)$. According to Burhop's calculations for element 47 (silver), the relative numbers of electrons in these three groups should be approximately in the proportion 1 : 3·4 : 6·7.

Electrons of Groups II and III were in fact recorded, with about the right relative intensities, by Robinson and Cassie[2] in a paper published in 1926 and quoted by Burhop. The less intense Group I was not observed in the 1926 experiments, but as its appearance—or non-appearance—is a matter of rather special interest, I wish now to point out that it was recorded in some later experiments of Robinson and Young[3], which have been overlooked by Mr. Burhop.

The special interest attached to this particular group lies in the fact that $L_{\mathrm{I}} \rightarrow K$ is a forbidden transition in the X-ray spectral series scheme ($\Delta l = 0$, in the $nlj$ notation for levels). Its appearance in our experiments and in the β-ray spectra of Ellis establishes experimentally a fundamental difference between the elementary processes which constitute the Auger effect, and the only alternative set of processes which could be invoked to explain the occurrence of photo-electrons of the second kind, namely, the production and internal absorption of the characteristic X-radiation of the atom.

In our experiments of 1930, the Auger electrons of Group I were not very clearly photographed. Since then, in the course of work on a different problem, and using an improved photographic technique, I have occasionally obtained very much better records of Auger electrons. One particularly good example may be quoted here, as it has not previously been published. The element under examination was copper (29); the velocities of the electrons are deduced from deflections in a magnetic field, and expressed[4] in terms of $(rH)$ gauss cm. These are converted into equivalent frequencies ($\nu/R$ in Rydberg units) by the use of known constants, and hence by comparison with X-ray data the level of origin of the electron can be deduced with certainty.

| Relative Intensity | $rH$ | $\nu/R$ | Type of Electron |
|---|---|---|---|
| 1 | $277{\cdot}4_0$ | 495·9 | Group I |
| 5 | $280{\cdot}4_3$ | 506·7 | Group II |
| 8 | $283{\cdot}7_7$ | 518·8 | Group III |

The agreement with the theory is striking. I think I should add that my own sense of satisfaction with the results is if anything enhanced by the feeling that it may be slightly unmerited; the approximations made in the quantum mechanical theory and—not less—the necessary latitude in my estimates of relative intensities, might well account for differences between experiment and theory appreciably greater than those recorded above. The general nature of the experimental results, however, leaves no room for reasonable doubt of the essential accuracy of the quantum mechanical methods which have been applied to the problem.

H. R. Robinson.

Queen Mary College,
University of London.
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[1] Burhop, E. H. S., *Proc. Roy. Soc.*, A, **148**, 272, February 1935.
[2] Robinson and Cassie, *Proc. Roy. Soc.*, A, **113**, 282; 1926.
[3] Robinson and Young, *Proc. Roy. Soc.*, A, **128**, 92; 1930.
[4] cf. Robinson and Cassie or Robinson and Young, *loc. cit.*

## Supra-conducting Alloys

The behaviour of supra-conducting alloys has been found[1] to be different from that of pure metals in two ways:

(1) The magnetic induction ($B$) in alloys does not change to zero when they become supra-conducting.

(2) A supra-conducting alloy shows no discontinuity in the specific heat of such an order as would be expected according to Rutgers' formula[2].

These phenomena seem to be well established, as more recent experiments by de Haas and Casimir[3] and Tarr and Wilhelm[4] are in agreement with (1), while Shubnikow and Chotkewitsch[5] succeeded quite recently in confirming our result (2).

We measured the permeability of the same alloy the specific heat of which we determined and found that magnetic flux could penetrate it at much lower fields than the threshold values of supra-conductivity (compare ref. 3). That means that the condition $B = 0$ on which Gorter's[6] thermodynamical treatment is based is not entirely fulfilled in supra-conducting alloys and therefore Rutgers' formula must not be applied. In order to investigate the supra-conducting region where $B \neq 0$ (shaded, Fig. 1), we determined the change of induction which corresponds to a small change $\triangle H$ in the external field between $T_1$ and $T_2$ in rods of $Pb_{30\%}$ $Bi_{70\%}$. Curve 1 is the threshold curve from a very similar alloy[7], while curve 2 indicates the field strengths at which flux first penetrated the alloy.