Electron traps and dielectric changes in phosphorescent solids

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REFERENCES


The effect of temperature on the intensity of X-ray reflexion.

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The effect of temperature on the intensity of X-ray reflexion by gold, copper and aluminium has been studied by making microphotometric measurements on lines in X-ray structure spectra obtained with powder specimens in a Debye-Scherrer camera. A special method was employed to make cylindrical powder specimens, 0.3 mm. in diameter, which held together without adhesive and were free from a core of foreign material. The primary beam was standardized by means of a flat-plate X-ray camera, furnished with a plate of powdered gold which provided a spectrum whose lines could be accurately measured. The powder specimen under investigation was maintained in vacuo at temperatures ranging up to about 900° K, and its temperature estimated from lattice parameter measurements.

The observed fall in intensity of X-ray reflexion by gold and copper as the temperature is raised up to about 900° K can be accounted for if the characteristic temperature varies with temperature in accordance with the relation \( \Theta_T = \Theta_1 [1 - \gamma(T - T_1)] \), where \( \Theta_T \) and \( \Theta_1 \) are the characteristic temperatures at temperatures \( T \) and \( T_1 \), \( \alpha \) is the cubical coefficient of thermal expansion and \( \gamma \) is the Gruneisen constant. This relation is found to hold also for aluminium up to about 600° K. Beyond 600° K the fall of intensity exceeds that to be expected from the above relation, and it is suggested that another factor becomes prominent in the case of aluminium at the higher temperatures.

The characteristic temperatures of gold, copper and aluminium now found by X-ray measurement at different temperatures, agree with the values obtained at those temperatures by specific heat and electrical conductivity methods.
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It was shown in a previous paper (Owen & Edmunds 1945) that, by taking particular care in the preparation of the powder specimen, a fibre X-ray camera may be employed for the investigation of the relative intensity of lines in structure spectra. In that investigation the lines in photographs taken with copper and gold at room temperature were measured. The study of the effect of temperature on the intensity of X-ray reflexion introduces difficulties which were not encountered in measurements made with material at room temperature, the chief of these being the standardization of the X-ray beam, which is necessary before the comparison of reflexions at different temperatures can be made. The measurement of the temperature of the specimen presents no particular difficulty, because with materials the thermal expansions of which have been thoroughly established, this can be accomplished by measuring the lattice parameter. To enhance the accuracy of the measurement of line intensity, special precautions have to be taken in order to obtain structure spectra with as clear a background as possible.

For the photographic basis of the work reference should be made to the paper already referred to; the relation between blackening of the film and the quantity of X-rays falling upon it is there fully investigated. It was found with the technique adopted that it was safe to assume a linear relation between these quantities for values of the blackening up to 0·8 unit; for higher values of blackening the linear relation no longer holds. It was therefore important to keep within the above degree of blackening when making measurements of line intensity.

The microphotometry of lines in the X-ray photographs enables the variation of the intensity with temperature to be determined, and the results can be compared with the prediction of the theoretical formulae developed by Debye & Waller. An important quantity in Debye's theory is the characteristic temperature \( \Theta \), and the most instructive way in which the experimental results can be compared with the results of the Debye-Waller theory is to calculate values of the characteristic temperature from them. In this paper we have attempted to do this for gold, copper and aluminium.

Experimental

The apparatus is so designed that the specimen can be maintained, \textit{in vacuo}, at any desired temperature between room temperature and about 600\degree C. The camera itself remains at room temperature during the exposure. In order to standardize the X-ray beam use is made of the flat-plate camera which is kept at room temperature, and an exposure is made with this camera simultaneously with the fibre camera.

The arrangement of the apparatus is shown diagrammatically in figure 1. The specimen is mounted at \( S \) and can be rotated continuously during exposure to X-rays by means of a clock mechanism, the housing of which is indicated by the rectangles \( P \) in the diagram. It is held vertically in a small electrical furnace \( F \) which is wound in two halves, with a gap between them to allow the middle of the specimen to be exposed to the X-ray beam. The whole is enclosed in the cylindrical
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chamber C, which can be evacuated. Outside this chamber, the camera A is mounted. This can be removed without disturbing the rest of the apparatus, and can be replaced again in exactly the same position on its hole, slot and plane mounting. The X-ray beam was arranged to pass symmetrically through the slit system.

On the other side of the X-ray tube T is mounted the flat-plate camera B, which receives the X-ray beam passing through the window W. The cameras A and B are situated in the same horizontal plane, and the mounting of the camera B is fixed rigidly in relation to the tube, but the camera itself can be removed from its hole, slot and plane mounting and replaced again in the same position without disturbing any other part.

The whole assembly to the left of the target (figure 1), including the furnace in its vacuum enclosure and the fibre camera A, is mounted on a platform on wheels fitted with roller bearings, and can be moved along rails away from the tube, in order to facilitate manipulation of the camera and its accessories, when a new fibre has to be mounted inside the chamber. It is essential, however, that during a series of exposures at different temperatures with any one specimen, the relative positions of the X-ray tube and the two cameras should be maintained. The construction of the apparatus is such that this condition is satisfied.

To enable the X-rays reflected from the specimen to reach the camera A, a slit about half an inch wide, covered with thin cellophane, is made in the cylindrical chamber at the proper height. The entrance and exit holes M and N in the chamber are also rendered vacuum-tight by means of a cellophane covering. To keep the joint between the cellophane and the brass surface cool, two annular water chambers (not shown in the diagram) arranged within the main chamber, have cold water circulating through them. To absorb water vapour small glass vessels filled with phosphorus pentoxide are placed on the floor of the chamber. The projecting tube

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D attached to the camera provides a suitable mounting for a fluorescent screen to find if the specimen is mounted centrally in the X-ray beam. The screen is removed during an exposure to allow a free exit to the beam.

Before commencing an exposure at elevated temperature, a steady current is allowed to flow for half an hour through the heating furnace. That this was a sufficiently long period for the specimen to attain a steady state was proved by the fact that sharp doublets in the precision range of the camera were obtained; also these doublets displayed no disymmetry such as would result if an appreciable temperature gradient existed in the part of the specimen exposed to the X-ray beam.

The current through the furnace was maintained at a constant value throughout a given exposure. There was no need to calibrate the furnace for temperature because each high-temperature film was made to serve as its own thermometer.

The quality of the films obtained with the fibre camera depends to a great extent on the slit system employed, both as regards the attainment of good resolution and the avoidance of scattered radiation. The slit system is divided into two parts—the hole in the block $H$ (figure 1), which is fitted into the camera, and the hole in the block $E$ carried by the mounting of the furnace. By taking special measures to shield the film, it was possible to obtain a clear background all along its length. Such background as still existed was mainly due to the occurrence of absorption edges and could, of course, not be eliminated. The mean radius of the fibre camera was 96.21 mm. A series of fiducial marks enabled corrections to be made for film changes on processing.

The preparation of the fibre has been described in the paper already quoted. It requires much patience and care in manipulation to produce a satisfactory fibre, but when made it is accurately cylindrical, holds together without adhesive and is free from any core of foreign material. After the specimen has been annealed to remove the effect of cold work done on the filings, it can be more easily handled and adjusted in the camera mounting; adjustment is necessary so that the specimen may be rendered free from wobble when it is rotated, otherwise the definition of the lines in the photographs is not satisfactory.

Materials of the highest purity were used in the investigation. The size of the crystallites in the specimen is important; only those particles passed by a sieve of 350 mesh and rejected by a sieve made with two layers of 350 mesh gauze, displaced relative to one another through half a diagonal of a mesh, were used. This procedure resulted in some degree of uniformity of particle size. The ideal size of particle is that with which there is no appreciable amount of primary extinction, and at the same time no particle scattering. As in the previous work, particle size was considered to be satisfactory if the lines in photographs obtained when the specimen was not rotated were free from spottiness, and did not display undue broadening. To reduce error arising from background discontinuities, it is also important to obtain well-defined reflexion lines, and this implies the use of a crystalline specimen in good equilibrium, as free from wobble as possible when it is rotated, and a sharp tube focus. All these conditions were striven after and to a great measure secured.
The effect of temperature on the intensity of X-ray reflexion

One of the salient features of the present work is the employment of the flat-plate camera to serve as an index of the output of characteristic radiation by the X-ray tube. Need for such an index arises from the fact that to obtain results which can be compared with theoretical prediction, fibre camera exposures at elevated temperatures have to be compared with exposures made at room temperature. No useful information can be obtained from these exposures unless the performance of the tube can be specified for each exposure. In the present investigation the assumption is made that the output of characteristic radiation from the tube divides itself in a constant ratio between the two cameras, and there is ample experimental evidence that this is a legitimate assumption, so long as the target of the tube is not pitted, and precaution was taken that this did not occur.

For details of the flat-plate camera used, reference should be made to the previous paper (Owens & Edmunds 1945). In the preparation of the crystalline powder plate, certain factors have to be attended to in order to obtain lines of uniform intensity. The size of the particles must be small and the distribution of the crystal planes sufficiently random to ensure that the lines are free from spottiness. In the present work a gold flat plate was used throughout; the filings were prepared so as to obtain uniformity of size in the manner already indicated for the fibre specimen, and were annealed before use. The actual surface of gold measured about 10 by 7 mm.

It is to be noted that with the flat-plate camera, a reflected line for which the glancing angle $\theta$ is equal to the angle ($\alpha$) between the beam and the plate, will be sharply focused, but other lines for which $\theta$ is not equal to $\alpha$ will be out of focus and of appreciable breadth. At first sight, this characteristic feature of the flat-plate camera appears to be a grave disadvantage, as, indeed, it would be were one concerned with the position of the lines and not with their intensities, but for intensity measurements it is of great value, as in the out-of-focus lines the reflexion is spread out over an appreciable angle and consequently a line can be quite intense without exceeding the limit of the film calibration and can, therefore, be photometered accurately. The accuracy is also improved by the profiles of the out-of-focus lines, which are found to have steep sides and more or less flat tops, and are, therefore, well suited for micro-photometry (Brentano 1935; Brindley & Spiers 1934).

It was necessary to cut down the beam entering the flat-plate camera so that when the longest exposure was made with the fibre camera—which occurred when the specimen was maintained at the highest temperature of which the apparatus was capable—the density of the lines on the flat-plate film would be just within the limit permitted by the calibration curve for the film. The X-ray beam was, therefore, passed through appropriate filters, which also eliminated the $\beta$-lines. This procedure makes for maximum accuracy in fixing the intensity level of the exposure.

Ten lines were seen in the photographs obtained with the flat-plate camera, with copper $K\alpha$ radiation, when the value of the angle $\alpha$ is 36°. Of these, three, namely the lines for which $\sum h^2$ is 8, 11 and 12, were selected as the standard lines, the sum of their intensities being taken as proportional to the intensity of the $K\alpha$ radiation passing into the flat-plate camera.
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It was arranged that each photograph taken when the fibre was maintained at elevated temperature was bracketed between two photographs taken when the fibre was at room temperature. The intensities of the lines were all brought to the same level by calculating their values per unit intensity of radiation entering the flat-plate camera.

It may be added that in processing the photographic films, precaution was taken that the films from both the fibre and the flat-plate cameras were given identical treatment; they were developed together in a small tank, especially made for the purpose, in which the films were held in position, close together but not touching, thus ensuring that they were developed at the same temperature.

The instrument available for measuring the intensities of the X-ray lines was a Moll, type B, recording microphotometer, which had been modified in the laboratory so that it could be used as a ‘null’ instrument. This was effected by employing a wedge with a linear calibration curve of density gradation along it. Owing to the sensitivity, stability and excellent dead-beat qualities of the Moll galvanometer, readings with the wedge method could, with confidence, be taken in quick succession. One advantage of the null method over the original recording method is the ease with which check readings of the zero can be made, thus removing uncertainty with regard to galvanometer creep; another advantage is that the curves can be recorded on a magnified scale, which helps to increase the accuracy of measurement. The areas of the peaks were determined by means of a planimeter.

To obtain consistent results in photometering the films it was necessary to pay particular attention to the mounting of the films on the film carriage, so that all the lines were photometered always at the same level. Only lines occurring at large values of glancing angle were measured, for these lines display the greatest change of intensity with change of temperature.

Theoretical

The intensity of a line recorded on a powder photograph depends on a large number of factors. In a fibre camera of radius \( r \), suppose there is a volume \( V \) of crystalline powder exposed to the incident X-radiation which is of intensity \( I_0 \). Then the diffracted energy \( P \) which gives rise to a line of length \( l \) on the film is given by the following expression:

\[
\frac{P}{I_0} \equiv R = \frac{\lambda^4 e^4}{16\pi m^2 c^4 r^4} p V N^2 F_T^3 \frac{1 + \cos^2 2\theta}{\sin \theta \sin 2\theta} A = B A V \psi(\theta) N^2 F_T^3. \tag{1}
\]

\( \lambda \) is the wave-length of the X-rays; \( N \) is the number of unit cells per unit volume of the crystal, and the symbols \( e, m \) and \( c \) have their usual significance. \( B \) is a constant and includes \( p \), the multiplicity factor for the crystal planes \((hkl)\) corresponding to the glancing angle \( \theta \), which is a constant since only one line is considered at a time, and \( \psi(\theta) = \frac{1 + \cos^2 2\theta}{\sin \theta \sin 2\theta} \). The quantity \( A \) is the absorption factor, data for
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The calculation of which for a crystalline mass in the form of a cylindrical rod have been tabulated by Bradley (1935).

$F_T$, the scattering factor at temperature $T$, refers to the scattering from a unit cell of the crystal, and it is related to the scattering factor at absolute zero, $F_0$, by the relation $F_T = F_0 e^{-M}$, where $M$, in the case of a crystal composed of atoms of one kind arranged at the points of a cubic lattice, is given by the expression

$$M = \frac{6h^2}{mk\Theta} \left( \frac{\phi(x)}{x} + \frac{1}{4} \left( \frac{\sin \theta}{\lambda} \right)^2 \right),$$

(2)

where $\Theta$ is the characteristic temperature of the crystal and $x = \Theta/T$, $T$ being the absolute temperature. Values of $\phi(x)$ for different values of $x$ have been calculated by Debye. The term $\frac{1}{4}$ inside the bracket is consequent upon the assumption of the existence of zero point energy. In the present work only a very slight difference is introduced into the result if this term is omitted.

Since inquiry is being made into the effect that change in temperature of the crystalline mass will have on the intensity of a line in the powder photograph, the values that various quantities have at the ‘standard’ room temperature (i.e. 293° K) will be denoted by the suffix 1 and the values at an elevated temperature $T$ by the suffix $T$. Thus by combining the above relations one arrives at the following working formula:

$$Y \equiv \left( \frac{\lambda}{\sin \theta_T} \right)^2 \left[ \log_e \frac{R_T}{R_1} - \log_e \left( \frac{A_T V_T \psi(\theta_T) N_T^2 (F_0^2_T)}{A_1 V_1 \psi(\theta_1) N_1^2 (F_0^2_1)} \right) \right] = \frac{12h^2}{mk^2\Theta} \left( \frac{\phi(x_T)}{x_T} - \frac{\phi(x_1)}{x_1} \right).$$

(3)

This enables the predictions of theory with regard to the dependence of line intensity on temperature to be compared with the results of experiment. Furthermore, it separates the effect due to increased thermal motion of the atom in the lattice from the effects due to changes in absorption, volume of specimen, glancing angle, and number of unit cells per unit volume, and the slight change in value of $F_0$ owing to change in angle of reflexion, this being quite apart from the variation of $F$ with temperature as expressed by the relation $F_T = F_0 e^{-M}$. These changes may be regarded as corrections which must be applied to the experimentally determined ordinate before this can be compared with the results of theory. Since the term on the right-hand side of the above relation does not involve $\theta$, it is clear that if at a given temperature the corrected expression $(\lambda/\sin \theta_T)^2 \log R_T/R_1$ is evaluated for various lines on the film, these values should be constant. This was found to be the case within experimental error.

In the above relations the characteristic temperature is assumed to be independent of the temperature. If it varies with temperature one may proceed as follows. The crystal lattice alters its dimensions with change of temperature, and if the Einstein model of a solid is assumed, an expression can be obtained for the thermal coefficient of expansion, which may be thrown into the following form (Mott & Jones 1936):

$$\frac{\alpha V_0}{X_0 C_v} = -\frac{d(\log \nu)}{d(\log V)} \equiv \gamma,$$
when \( \alpha \) is the coefficient of thermal expansion, \( V_0 \) the volume of 1 g. of the solid, \( \chi_0 \) the compressibility at zero temperature, \( C_v \) the specific heat, and \( \nu \) the frequency of the atoms in the lattice. \( \gamma \) is the Gruneisen constant and is independent of temperature; its value for a given material may be calculated from the experimental values of \( \alpha, \chi_0 \) etc., at any convenient temperature. For gold, copper and aluminium, it has the values 3.03, 1.96 and 2.17 respectively.

Since, in the Einstein distribution function, \( h\nu = k\Theta \), it follows that

\[
d(\log \Theta) = -\gamma d(\log V),
\]

so that

\[
\Theta = \text{const.} \, V^{-\gamma}.
\]

Since

\[
V_T = V_1[1 + \alpha(T - T_1)],
\]

then

\[
\Theta_T = \Theta_1[1 - \alpha\gamma(T - T_1)],
\]

where \( \Theta_T \) and \( \Theta_1 \) are the characteristic temperatures at \( T \) and \( T_1 \).

Since \( \Theta \) now varies with temperature, then

\[
Y_1 = -\frac{12h^2}{mk} \left( \frac{1}{\Theta_T} \frac{\phi(x_T)}{x_T} - \frac{1}{\Theta_1} \frac{\phi(x_1)}{x_1} \right).
\]

Using the approximate form \((1 - K_1 x)\) for \( \phi(x) \), where \( K_1 \) is a constant, substituting the value of \( \Theta_T \) in terms of \( \Theta_1 \), and neglecting terms of second order, then, finally,

\[
Y_1 = -\frac{12h^2}{mk} \frac{1}{\Theta_1^2} (T - T_1) (1 + 2\alpha\gamma T).
\]

When the values of \( Y_1 \) given by this relation are plotted against the absolute temperature, we get a curve which is concave to the temperature axis.

If the characteristic temperature were independent of temperature, then, on the above assumptions,

\[
Y = -\frac{12h^2}{mk} \frac{1}{\Theta_1^2} (T - T_1),
\]

so that

\[
Y_1 = \frac{1}{Y} (1 + 2\alpha\gamma T).
\]

There is a small correction to be made owing to the variation of \( \alpha \) with temperature. This relation can be applied to the experimental results now obtained either by calculating values of \( Y \) from the observed values of the experimental ordinate at different temperatures, and finding if they fall on a straight line, or otherwise by assuming a definite constant value of the characteristic temperature, calculating values of \( Y_1 \) at different temperatures and finding how well they fit the experimental curve.

**Results**

The mean values of the corrected experimental ordinate at different temperatures for gold, copper and aluminium obtained in the present investigation are given in table 1. The probable error of these values is estimated to be about \( \pm 5\% \).
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Table 1

<table>
<thead>
<tr>
<th>gold</th>
<th>copper</th>
<th>aluminium</th>
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<tr>
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<td>corrected experimental</td>
<td>corrected experimental</td>
</tr>
<tr>
<td>temp. °K</td>
<td>ordinate $(Y_1/2\cdot303)$</td>
<td>temp. °K</td>
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<td>293</td>
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<tr>
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<td>398</td>
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<td>785</td>
<td>-0·976</td>
<td>851</td>
</tr>
</tbody>
</table>

Gold

With gold there was little risk of surface contamination at high temperatures. Four lines only, corresponding to the highest glancing angles, were photometered for intensity measurements, but each side of the photograph was treated separately, thus yielding eight intensity measurements for each exposure. Knowing the temperature, the various corrections were readily calculated and the corrected experimental ordinate for each reflexion obtained. The values for each temperature were reasonably constant as expected by theory. In figure 2 the curve $A$ is the straight line obtained on the assumption that the characteristic temperature of

![Figure 2. Gold.](http://rspa.royalsocietypublishing.org/image)
gold is $175^\circ K$ and that it is independent of temperature. The open circles represent the observed points, and the crosses are the points calculated from curve $A$ by using relation (5). The dotted curve passes through the calculated points, and it is also the best curve that can be made to fit the experimental points. It may therefore be concluded that the characteristic temperature of gold at room temperature (i.e. $293^\circ K$) is $175^\circ K$, and that its value at other temperatures, up to $900^\circ K$, may be calculated by means of relation (4).

**Copper**

It was important when working with copper that the highest vacuum was maintained and that there was freedom from moisture. The conditions of experiment were such that after many exposures at high temperatures the copper showed but slight tarnish. Several specimens were employed in the course of the investigation, and the results obtained with these were consistent one with the other.

The experimental values are represented by the open circles in figure 3. In the preliminary stages a smooth curve was drawn through these points, and from this curve the values of the experimental ordinate, assuming the characteristic temperature to be independent of temperature, were calculated by means of relation (5). A rough idea was thus obtained of the value of the characteristic temperature at room temperature. The best value was found to be $314^\circ K$. Calculating $Y_1$ from the straight line corresponding to $\theta = 314^\circ K$, the points marked with crosses were obtained, and the curve through these points is again the best curve through the experimental points. Thus the experimental determination of the ordinate supports the conclusion that the characteristic temperature obeys relation (4), and that the value of the characteristic temperature for copper at $293^\circ K$ is $314^\circ K$.

![Figure 3. Copper.](image)
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Aluminium

Measurements on the variation of the intensity of X-ray reflexion by aluminium with change of temperature have already been carried out over the range from liquid-air to room temperature (James, Brindley & Wood 1929). Also several specific-heat determinations have been made, especially at low temperatures.

A single series of exposures was made comprising eight room-temperature exposures and seven at elevated temperatures, and the experimental conditions were favourable for accurate determinations of the experimental ordinate. The copper target used in the X-ray tube for the other two elements examined, was, with aluminium, changed for a cobalt target, in order to secure lines favourably placed for accurate parameter determinations. To standardize the X-ray beam lines in the flat-plate camera, photographs for which the values of $\Sigma h^2$ were 4, 8 and 11 proved suitable. In exposures at the highest temperatures line 4 was almost invariably too heavily exposed, thus invalidating the calibration law of the film. In these cases lines 8 and 11 were found to be quite adequate to fix the intensity of the primary beam.

The values of the experimental ordinate corrected for all errors are included in table 1. When plotted they fall on a curve (curve $B$ in figure 4) which exhibits a more pronounced curvature than the curves obtained with gold and copper. The value of the experimental ordinate shows a rapid fall in the region of the highest temperatures reached.

![Figure 4. Aluminium.](image)

Proceeding along the same lines as before, a value of $395^\circ$K for the characteristic temperature of aluminium at room temperature yields the curve $C$ when relation (5) is employed. The curve follows curve $B$ from room temperature up to about
600°C, but beyond this temperature the values of the experimental ordinate decrease much more rapidly than the calculated values do. From the agreement between the observed and the calculated values of the experimental ordinate from 293 and 600°C, on the assumption that at room temperature the characteristic temperature of aluminium is 395°C, it may be concluded that over this restricted range the characteristic temperature of aluminium obeys relation (4) as do gold and copper.

The rapid fall in intensity of the reflected beam as the temperature of aluminium is raised beyond 600°C requires explanation. It is possible that this decrease of intensity may be due to the removal of energy from the primary beam to form extra reflexions, the intensities of which become very strong in the case of aluminium at the higher temperatures.

The foregoing results show that the variation of characteristic temperature with temperature is represented satisfactorily by relation (4) over the range of temperature investigated. This relation cannot hold for temperatures below a certain limit, which will vary for different elements, but it was of interest to find how far the range over which it would be applicable could be extended below room temperature. Accordingly, it was employed to calculate the characteristic temperatures at the mean temperatures used in some previous investigations at low temperatures. These values are included in table 2 together with the experimental values, and, in the few instances cited, it is found that there is fair agreement between them. It would appear that the relation holds for gold and copper down to about 100°C and for aluminium down to about 10°C.

**Table 2**

<table>
<thead>
<tr>
<th>metal</th>
<th>mean temp. °C</th>
<th>calculated observed</th>
<th>method</th>
<th>authority</th>
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<td>186</td>
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<tr>
<td></td>
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<td>178</td>
<td>175</td>
<td>e.c.</td>
</tr>
<tr>
<td>Cu</td>
<td>100</td>
<td>320</td>
<td>320</td>
<td>s.h.</td>
</tr>
<tr>
<td>Al</td>
<td>10</td>
<td>414</td>
<td>419</td>
<td>X-ray</td>
</tr>
<tr>
<td>Al</td>
<td>190</td>
<td>402</td>
<td>403</td>
<td>J.B. &amp; W.</td>
</tr>
</tbody>
</table>

s.h. = specific heat.  e.c. = electrical conductivity.

**Table 3**

<table>
<thead>
<tr>
<th>temp. °C</th>
<th>characteristic temperature (°K)</th>
</tr>
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<tbody>
<tr>
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<td>gold</td>
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<tr>
<td>10</td>
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</table>
The effect of temperature on the intensity of X-ray reflexion

The results of this paper may be summarized by giving the values of the characteristic temperatures of the three elements gold, copper and aluminium, at different temperatures, basing these on the room-temperature values found in the course of the investigation and employing relation (4) to find them at other temperatures. They are collected in table 3. The decrease in the value of the characteristic temperature as the temperature is raised, is 2·2, 3·1 and 6·8°K per 100°K rise of temperature for gold, copper and aluminium respectively.

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REFERENCES


On the theory of dielectric breakdown in solids†

BY H. FRÖHLICH, H. H. WILLS PHYSICAL LABORATORY, UNIVERSITY OF BRISTOL

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It is shown that the theory of dielectric breakdown in solids previously developed by the author is correct only below a critical temperature $T_c$. This temperature is defined in such a way that above $T_c$, the density of electrons (in strong fields) is so high that mutual collisions between electrons are more frequent than collisions between electrons and the lattice vibrations. In the presence of strong external fields this leads to an equilibrium distribution of the electrons at an electronic temperature $T$ which is higher than the lattice temperature $T_l$. $T$ is determined by the energy balance according to which the rate of energy transfer from the field to the electrons must be equal to the rate of energy transfer from the electrons to the lattice vibrations. It is shown that equilibrium can be obtained only if the field is below a critical field $F^*$. For stronger fields the electronic temperature $T$ rises steadily until the crystal breaks down. It is found that $F^*$ decreases exponentially with increasing lattice temperature.

The theory now accounts for the rise of dielectric strength with temperature at low temperatures (previous theory) and for its decrease at high temperatures. It also shows why influences which tend to increase the dielectric strength at low temperatures (e.g. admixture of foreign atoms) tend to decrease it in the high-temperature region.

The increase of the electronic temperature with the field strength $F$ leads (for $F < F^*$) to an increase of electronic conductivity with $F$ which is calculated quantitatively.

† Based on Report L/T 153 of the British Electrical and Allied Industries Research Association (E.R.A.).