spark line and obtained good agreement (Table I) with the plane grating results.

The agreement between various ruled grating experiments is actually much better than is obvious from the published reports. This is due to the fact that different crystal constants have been assumed in different reports. In Table I the percent differences between the ruled grating and the crystal values have been recalculated for the best absolute measurements using[5] $d_\infty = 3.02810$A. The numbers in parentheses are the numbers of independent determinations entering into that particular value. Thus when all the results are referred to the same crystal standard the agreement is very good. The weighted average was obtained by giving each result a weight equal to the number of independent values entering into that particular result. Bäcklin's 1928 result was neglected since his improved technique gave a very much higher value.

Since the many tests made on crystals normally used for x-ray work have indicated no mosaic structure one should be justified in using the absolute x-ray data for calculating some of the fundamental constants. The true x-ray grating constant of calcite crystals which is independent of any theory of crystal imperfection is

$$d_\infty = 3.03560 \pm 0.00005\text{A}.$$

Avogadro's number is

$$N = 6.0220 \pm 0.0005 \text{ mole/mole}$$

and using the Faraday $= 9648.9$, one obtains the charge on the electron

$$e = 4.8036 \pm 0.0005 \times 10^{-10} \text{ e.s.u.}$$

The value of Planck's constant as determined from the continuous x-ray spectrum is

$$h = 6.607 \pm 0.001 \times 10^{-27} \text{ erg. sec.}$$

These values of the fundamental constants differ by 0.75 to 1.0 percent from the present accepted values. Since the three independent methods of determining x-ray wavelengths agree so well it appears that the true scale must be the ruled grating value and not the crystal values. The writer's attempts to use the above values of N, e and h in the interrelationships of the physical constants have not given satisfactory results. Thus, while it appears that one should be able to determine accurately the values of N, e and h from the x-ray data, it does not seem possible at the present time to reconcile such values with existing data on these constants by other methods.

It is a pleasure to acknowledge my indebtedness to the American Academy of Arts and Sciences for funds with which to purchase the diamond prism, and to Professor R. W. Wood for his cooperation in the ruling of the gratings.

J. A. Bearden

Johns Hopkins University,
May 7, 1935.

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Radiative Auger Effect

The weak forbidden line in the K x-ray spectrum designated as β_5 by Idei[1] and as β_4 by Beuthe[2] has been studied by several workers[3] in the elements from vanadium (23) to antimony (51). It is a close doublet due to the transition $M_{33}M_{32} \rightarrow K$ and has an intensity ratio to α_1 of roughly 0.001. This faint line lies approximately midway between the strong lines β_1 and γ. If, in an effort to gain intensity, polished calcite crystals are used, the feet of the strong lines extend practically to the line β_5, but if etched calcite crystals[4] are used on a double crystal spectrometer with narrow horizontal slits the forbidden line is found in the middle of a broad, flat valley with a distinct plateau on the long wave side. This rise in the "continuous radiation" begins at β_5 and increases in steps until the total increase in ordinates about equals the height of the β_5 line. The phenomenon bears a superficial resemblance to a Compton effect with a very broad modified line.

Fig. 1 shows one set of measurements on molybdenum. The separation of the two components of β_5 indicated in

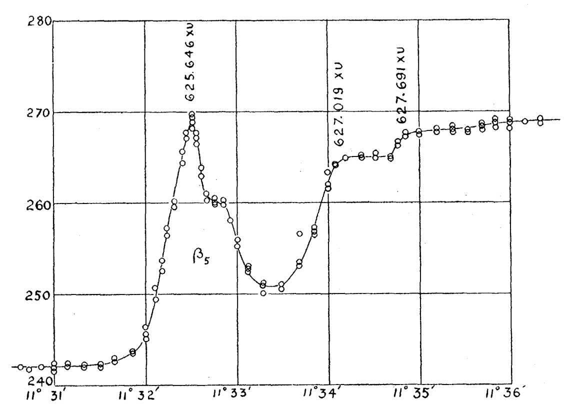

FIG. 1. Molybdenum $K\beta_5$. The strong lines β_1 and γ are at 11° 38′37″ and 11° 25′42″, respectively. The ordinates are electrometer deflections per minute.

this curve would seem to be somewhat too large to agree with accepted values of the $M_{33}M_{32}$ energies. Twelve curves have been run on molybdenum with different crystals, voltages, currents and targets. While slight erratic variations occur because of the faintness of the radiation, the essential characteristics are identical in all. Similar curves but with less precision have been obtained for rhodium, palladium and silver. In each case there is a rise in "background" on the long wave side of β_5, the upward slope extending for about 2 X.U. and then the plateau running with a flat top to β_1. This same peculiar phenomenon is shown in Duane's[5] high dispersion photographs of the Mo K spectrum as distinct increase in background extending from β_5 (called x by Duane) to β_1.

The explanation of this continuum on the long wavelength side of the forbidden line may be seen in the possibility of a radiative Auger effect, i.e., a simultaneous emission of a light-quantum and an electron by the excited atom. As one of us[6] has recently pointed out, such a process can occur by dipole-radiation, while the single electron transition $M \rightarrow K$ necessitates a quadrupole transition. In an elementary process in which the emitted electron leaves the atom with a kinetic energy E, we would expect a light-quantum to be emitted with a frequency

$$\nu = \nu_{M_1K} - (1/h)(E + I_\alpha),$$

where ν_{M_1K} is the frequency of the β_5-line, I_α the ionization-energy of the ejected electron. Since E, beginning with zero, can assume any positive value, the values of this frequency will likewise lie in a continuous range the high frequency limit of which is given by

$$\nu_{\max} = \nu_{M_1K} - I_\alpha/h.$$

We would interpret each step in the intensity-plateau reported above as the beginning of one such continuum, the short wavelength limit being different from electron groups with different ionization energies I_α. Thus in the case of Mo the continual joining the steps at a wavelength $\lambda = 627.019$ and $\lambda = 627.691$ would correspond to the ejection of an N_2 and N_1 electron, respectively. Expressing the difference in frequency from the step to the forbidden line $\lambda = 625.646$ in units of the Rydberg-frequency, one would thus obtain for the N_1 electron

$$(\nu_{M_1K} - \nu_{\max})_1 = I_{\alpha 1}/h = 4.75 \qquad (4.7)$$

and for the N_2-electron

$$(\nu_{M_1K} - \nu_{\max})_2 = I_{\alpha 2}/h = 3.19. \qquad (3.8)$$

These values are in satisfactory agreement with those given in the parentheses and determined from limiting frequencies of x-ray series.[7] It is important to notice that the mechanism here proposed yields also the right order of magnitude for the total intensity of the continuum. Taking only the contribution due to the emission of N_2 electrons, we would expect it[6] to stand to the intensity of the K-line in a ratio of about

$$6(e^4/E_\alpha^2)(r_i/r_\sigma^2)^2 \cong 0.2.$$

E_α is the ionization energy of an M_3-electron, the radii r_i and r_0 of the M_3- and N_2-orbits are estimated from the observed ionization-energies under the assumption of hydrogen-like orbits and the factor 6 is introduced to account for the presence of 6 N_2 electrons. Since the intensity of $K-\gamma$ is about 50 times the intensity of $K-\beta_5$ this means that the total intensity of the continuum would be about $50 \times 0.2 = 10$ times stronger than that of the forbidden line. This agrees with the experimental fact that the height of the plateau is approximately the same as that of the forbidden line; its extension however is about 10–20 times bigger.

F. Bloch
P. A. Ross

Stanford University,
April 22, 1935.

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The Thermodynamic Temperature Scale in the Region Below 1° Absolute[1]

In our first experiments[2] on the production of very low temperatures by adiabatic demagnetization Curie's law, $\chi T = \text{const.}$, was assumed in obtaining the temperature.

Nearly a year ago experiments to determine true thermodynamic temperatures were performed and since we have not yet found time to report these in detail, we wish to publish a brief account of our results here. The full account will be given later, probably in the *Journal of the American Chemical Society*.

The substance investigated was gadolinium phosphomolybdate, $Gd(PMo_{12}O_{40})_3 \cdot 30H_2O$. An 89.28 g sample was used for the measurements.

Hoard[3] has shown that this substance is cubic with the gadolinium atoms occupying positions corresponding to those of the diamond type lattice. Thus all gadolinium atoms are equivalent and since there is but one gadolinium in a total of 250 atoms the magnetic atoms are unusually well diluted. This minimizes the interactions which must at sufficiently low temperatures destroy the validity of Curie's law. This law is, in the limiting case, inconsistent with the third law of thermodynamics.

In a paper, soon to appear,[4] we have shown how the application of the first and second laws of thermodynamics to magnetic and calorimetric data will permit the correlation of magnetic susceptibility, field strength and temperature. Here we will mention only the results for the determination of temperature in the special case of zero magnetic field where $T = de/dS$.

Magnetic susceptibilities were measured by the inductance coil method.[2] The susceptibility could then be used as a reference in correlating entropy and energy measurements. The entropies were fixed by a series of isentropic demagnetizations which started at known temperatures and magnetic field strengths. This procedure has been described in connection with the determination of the heat capacity of $Gd_2(SO_4)_3 \cdot 8H_2O$.[2]

For fixing the energy it was desirable to avoid the use of the usual electrical connections because of heat leak. We considered many possible sources of heat input such as radiation from a filament, from ordinary temperatures or from a radioactive material, the addition of a small amount of solid of known energy content or the condensation of small amounts of helium gas. Although any of these methods might have been employed we finally decided to use an induction heater. The heater consisted of a closed loop of No. 40 (B. and S. gauge) gold wire about 2 cm in diameter. The gold contained 0.1 percent silver. A small current was induced in the heater by means of a relatively large 60-cycle current in the same solenoid magnet used for the demagnetizing process. Although the total amount of energy introduced for a measurement was about 0.001 calorie it could be determined to the order of about 10^{-5} calorie. The measurements showed that for all temperatures down to 0.30°K the Curie scale for gadolinium phosphomolybdate is within 0.01° of the true thermodynamic scale. However, at 0.25° (Curie) the Curie temperature was 5 percent too low; at 0.20°, 11 percent too