Then, unless we assume the validity of the Darwin-Ewald-Prins theory, we are at a loss to correct for the asymmetry of the crystal patterns and this state of affairs reduces the relative importance of an accurate slit-height correction. On the other hand, certain features of the theoretical patterns (but not asymmetries, which as yet cannot be directly checked by experiment) have been shown to give surprisingly good agreement with experimental measurements[4] in the $(1, -1)$ positions and it is likely that the actual pattern asymmetries are given qualitatively by the theory as indicated above. One hesitates to say the experimental crystal effects could be evaluated quantitatively because the theory is based on the assumption of a "perfect" crystal which does not actually exist. Perhaps it is best to apply the slit-height correction and await results of future researches to decide the crystal effects.

The above discussion applies also to wavelength measurements made photographically with a single crystal spectrometer when the appropriate divergence correction is substituted for Eq. (3). The crystal effects in this case are, of course, those due to a single crystal instead of the compound effect of two crystals.

LYMAN G. PARRATT*

Cornell University,
May 1, 1935.

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The Scale of X-Ray Wavelengths

In a further effort to settle the question concerning the crystal and ruled grating scale of x-ray wavelengths the writer has carried out two additional experiments. First, the refraction method has been perfected by using a large diamond prism. Second, large ruled gratings have been used with a double crystal spectrometer to measure the wavelength of the copper $K\alpha_1$ line.

It has been shown[1] that the refraction of x-rays may be used as a means of determining the true scale of x-ray wavelengths. In the previous measurements a quartz prism was used and the wavelengths obtained agreed with the ruled grating values. However, there was some uncertainty in the results because of the difficulty of correctly making allowance for the effective number of electrons in the silicon. The present experiment was designed to eliminate this by using a prism of low atomic number. A diamond fulfills all the requirements better than any other substance.

Thus photographic refraction measurements by the method[1] previously described by the writer have been made for the copper $K\beta$ line using the 90° edge of a perfect diamond block 9 mm×9 mm×3 mm. Two surfaces were polished optically flat and intersected in a very perfect edge, though later it was found possible not to allow any part of the x-ray beam to strike the edge. Fig. 1 shows a typical plate. The average of the results from 25 of the best plates is $\delta = 9.224 \pm 0.0005 \times 10^{-6}$. This gives for the wavelength on a $\lambda^{2.75}$ absorption law $\lambda = 1.3924$A. This is 0.26 percent greater than the best crystal value and is in good agreement with the ruled grating wavelengths as is shown in Table I.

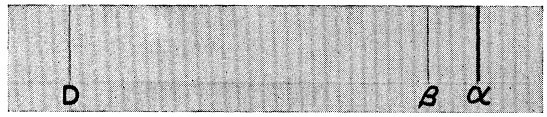

FIG. 1. D is the direct beam, β and α the refracted beams of the copper K series.

TABLE I. $(\lambda_g - \lambda_c)/\lambda_c$.

Observer	Grating	Cu $K\beta$	Cu $K\alpha$	Cr $K\beta$	Cr $K\alpha$	Al $K\alpha$
Bearden(1929)	a, b, c	0.24 (10)	0.25 (10)			
Bearden(1931)	1, c	.241(26)	.229(46)	0.239(16)	0.245(28)	
" "	4	.243(4)	.250(11)	.250(15)	.255(27)	
" "	4′	.264(30)	.257(49)	.253(3)	.254(5)	
" "	5	.246(41)	.234(73)	.235(32)	.239(51)	
" "	5′	.259(49)	.250(82)	.256(44)	.255(67)	
" "	6	.239(11)	.244(16)	.240(3)	.240(4)	
Bäcklin(1928)						0.17 (31)
" (1935)						.249(56)
Söderman(1935)			Cu $K\alpha_1$			.255(9)
Bearden(1935)	7		.253(8)			
" "	8		.247(4)			
" "	Refr.	.260(25)				
Weighted average 0.248±0.0016%						

One of the objections to the method of using plane gratings for x-rays is that one uses only a small number of lines. Thus in the second experiment a plane grating 75 mm long was used. The entire length was used by placing the grating between the calcite crystals of a double crystal ionization spectrometer. The angles of incidence and diffraction were then measured by the angular displacement of the second crystal. The crystals were set in the $(1, +1)$ position so that the reflected and diffracted lines were essentially in the $(1, -1)$ position. By this method the two most important angular measurements were made with lines which were only 11 seconds to 16 seconds wide. Four carefully calibrated microscopes were used to read the precision circle and since two lines, ten minutes apart, were read in each microscope, eight angular readings were obtained for each individual setting of the circle. Different parts of the circle were used in order to eliminate any errors due to possible erratic rulings on the circle. Two gratings were used, the first (7, Table I) was ruled with 100 lines per mm and the second (8, Table I) was ruled with 300 lines per mm. The average of all 12 results gives for the copper $K\alpha_1$ line, $\lambda = 1.5405$A. This is 0.25 percent greater than the corresponding crystal value and is in excellent agreement with the writer's previous results.[2]

Bäcklin[3] has recently repeated his earlier measurements on the Al $K\alpha$ line and now obtains results almost identical with the writer's 1929, 1931 and the present results. Also Söderman[4] has used a concave grating to compare a high order of the Al $K\alpha$ line with the first order of a known 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.

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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

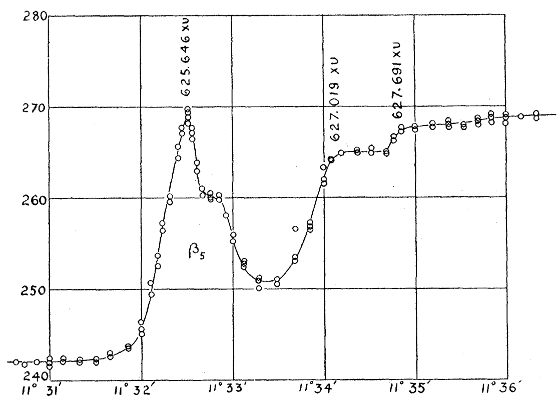

FIG. 1. Molybdenum $K\beta_5$. The strong lines β_1 and γ are at 11° 38′37″ and 11° 25′42″, respectively. The ordinates are electrometer deflections per minute.

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 › n 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

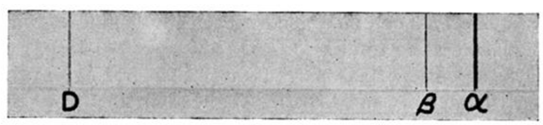

FIG. 1. D is the direct beam, β and α the refracted beams of the copper K series.