UNIVERSITY of TASMANIA

PART II LABORATORY WORK

KYA 211/212

Electron Diffraction

Last compiled 2026-04-02

Safety

Cathode tubes are thin-walled, highly evacuated glass tubes. Treat them carefully as there is a risk of implosion. Do not subject the tube to mechanical stresses and do not remove the tube from the holder.

Outline

Summary

A thin piece of highly-ordered material is considered as a diffraction grating, with the line widths determined by the atomic spacings in the sample. Observations of the diffraction patterns that result when electrons accelerated through several kilovolts hit a graphite target can be used to prove that electrons can exhibit wave behavior in accordance with de Broglie's hypothesis, and to probe the spacing and arrangement of the constituent carbon atoms on scales $\lesssim 10^{-9}$ m.

Experiment Objectives

1. **Primary:** To use the spacing of diffraction rings on a screen as a measurement of the spacing and orientation of carbon atoms within a graphite target.
2. **Secondary:** To observe the wave-like properties of electrons interacting with an ordered atomic lattice and to check de Broglie's predicted momentum-wavelength relationship for electrons.

Pre-lab Exercises

Pre-lab questions should be completed and submitted before you commence a new experiment. The information needed to complete the exercises is contained in the Background Theory Section, your course notes, or in the Appendices however, your own, independent research is highly encouraged. Make sure you include references where material has been sought elsewhere. This is not only "good form" but making notes of important information is essential if you then need to go back to that reference.

Task

1. The de Broglie wavelength of a particle is given by
$$\lambda = h/p$$
where h is Planck's constant, p is the particle momentum, and λ is the wavelength. h takes the value 6.626×10^{-34} J s $= 4.136 \times 10^{-15}$ eV s. What is the predicted wavelength of an electron with kinetic energy $K = 3$ keV? If a ray of light had this wavelength, in what part of the electromagnetic spectrum would it be?
2. The Davisson and Germer 1927 experiment was a breakthrough in the start of quantum mechanics. By showing that electrons scattered by the surface of a nickel crystal produce a diffraction pattern, they confirmed the de Boglie's hypothesis of wave-particle duality. The original paper published in *Nature* is in the appendix of these notes. The basic features of this experiment consisted of an electron beam directed perpendicularly onto the face of a crystal of nickel. A collector recorded the deflected electrons coming off the crystal at some angle ϕ to the normal. As noted in their paper, Davisson and Germer found particularly strong reflections at $\phi = 50^o$ for electrons accelerated through a potential of 54 V. By using the Bragg relation and de Broglie relation, determine the spacing of atoms in the surface layer of the nickel crystal. How does this value compare with the value determined from X-ray diffraction experiments (0.215 nm)?
3. In the experiment you will carry out, you will be using a piece of graphite as the target for the electron beam. Make an *estimate* of the spacing between atoms in a piece of graphite. Start by recalling that 12

grams of carbon-12 contains 6.022×10^{23} atoms, and the density of graphite is measured to be $\rho = 2.2$ g cm^{-3}. This is only a rough estimate because the packing of individual layers of graphite into a solid varies greatly from sample to sample. State any assumptions you must make to derive your result. You will be able to compare your experimentally found values later on.

4. Fig. 4 shows the geometry of the electron tube as the electron travels from the graphite tube to the fluorescent screen. Using this geometry, show that the angle α is given by

$$\alpha = \tan^{-1}\left(\frac{D/2}{(L-R)+\sqrt{R^2-(D/2)^2}}\right) \tag{1}$$

And show that you can obtain the following equation for α that depends on the voltage applied to electrons in the diffraction tube.

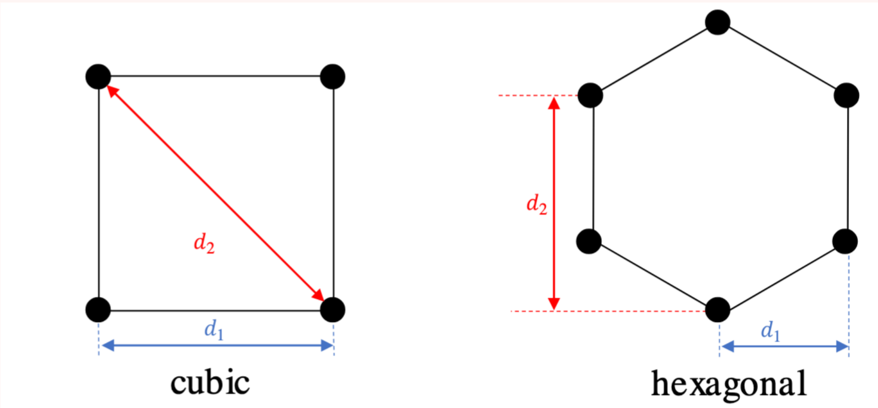
$$\sin\frac{\alpha}{2} = \frac{nh}{2d\sqrt{2q_e V m_e}} \tag{2}$$

Where h is Planck's constant, d is the atomic spacing, q_e is the electron charge, m_e is the mass of the electron and V is the applied voltage.

5. The figure below shows face-on geometries for a cubic (left) and hexagonal (right) crystal structure. If the crystal is cubic, for example, with adjacent atoms separated by some distance, then there is a characteristic distance d_1 between atoms, and a second characteristic distance between atoms diagonally across from each other, d_2. Each pair of atoms constitutes an aperture that can producte diffraction.

   (a) Using the figure blow, show that for a cubic crystal, the ratio $d_1 : d_2$ should be $\sqrt{2} : 1$

   (b) Show that a hexagonal crystal *also* creates effectively two relevant spacings, and that they are in the ratio of $\sqrt{3} : 1$.



Background Theory

One of the key principles of quantum mechanics is that matter exhibits wave-like behaviour. Einstein's work on the photoelectric effect showed that light, previously considered a wave phenomenon, also displays particle behaviour. In 1924, Louis de Broglie, then a graduate student, proposed in his doctoral thesis that if light can possess both wave-like and particle-like characteristics, perhaps matter could also exhibit wave-like properties. He derived an expression for the wavelength of matter, given by $\lambda = hp$, where h is Planck's constant and $p = mv$ represents momentum. This idea was groundbreaking at the time, as there was no experimental evidence supporting the wave-like nature of matter.

However, in 1927, Clinton Davisson and Lester Germer provided experimental confirmation of this phenomenon, specifically for electrons, in a discovery that occurred serendipitously. While investigating electron reflection from a nickel surface, they accidentally crystallised their target by heating it. They observed that the intensity of scattered electrons varied with the scattering angle, forming a pattern of maxima and minima. This indicated that electrons were undergoing diffraction by the crystal planes, much like light diffracts through a grating, resulting in constructive and destructive interference. Their findings were pivotal in solidifying quantum mechanics, earning Davisson and Germer the Nobel Prize. Moreover, electron diffraction has since become a vital technique for studying the structure of materials.

Consider a beam of electrons directed at a phosphorescent target. If the beam is not deflected, then it will produce a single bright dot where electrons impact the screen. If a diffusing target is placed in the beam line, then individual electrons will scatter off of atoms in the target, creating a slightly blurred spot on the screen. The atoms in the target are fixed in position, with some regular or irregular spacing, depending on the target material. If the electrons always behave as particles, then diffraction cannot occur and the pattern on the screen would resemble a Gaussian distribution. The pattern would change in intensity and width with increasing electron energy based on conservation of momentum applied to each electron-atom collision, but would always have a peak at the undeviated beam position and drop off smoothly with increasing scattering angle.

On the other hand, if the electrons can behave as waves, then if the spacing between target atoms is comparable to the wavelength of the electron "matter waves", we would expect to see a diffraction pattern caused by interference between electrons scattered by different atoms. According to de Broglie's hypothesis, the electron wavelength is inversely proportional to their momentum, and so the minima and maxima of the diffraction pattern should change regularly with electron momentum (and therefore, electron energy, which is directly controlled by the experimenter).

Diffraction with Crystalline Solids

The atomic structure of crystalline solids directly relates to the diffraction pattern produced when a sample of the solid is used as a diffraction grating for e.g. a beam of incident electrons or X-rays. The figure below shows how this can change drastically for crystalline silicon, polycrystalline silicon and quartz glass. In this lab, we are essentially going to perform crystallography on a sample of graphite using a focused beam of electrons.

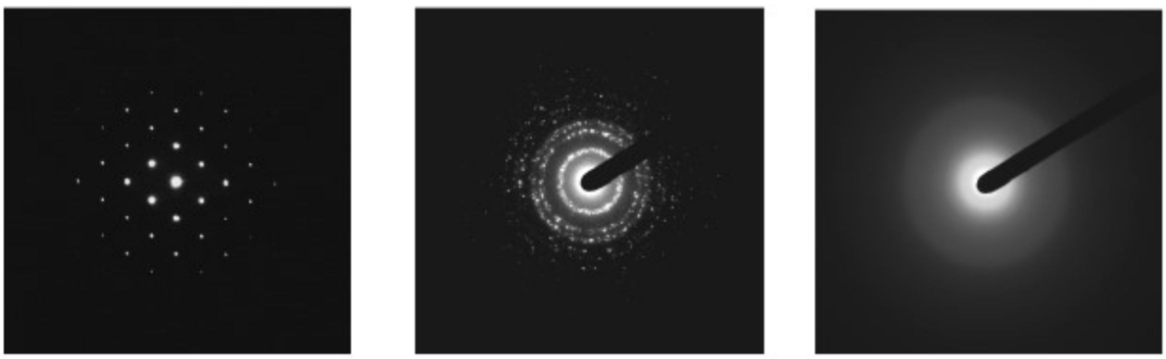


Figure 1: An example of electron diffraction patterns obtained for crystalline silicon (left), polycrystalline silicon (centre), and quartz glass (right).

In the pre-lab exercises you were asked to estimate the spacing of atoms in a piece of graphite. Assuming you have found that the spacing between graphite atoms is of the correct order of magnitude to demonstrate diffraction of an $\sim$3 keV electron beam, we can try to predict where we will see intensity maxima in the diffraction pattern, as a function of deflection angle and electron energy.

Shown below is a simplified version of diffraction from a crystal lattice. The basic equations for scattering in a crystal were derived by Bragg to describe the interaction of high-energy radiation with matter, and Bragg's Law gives us the means to test de Broglie's hypothesis.

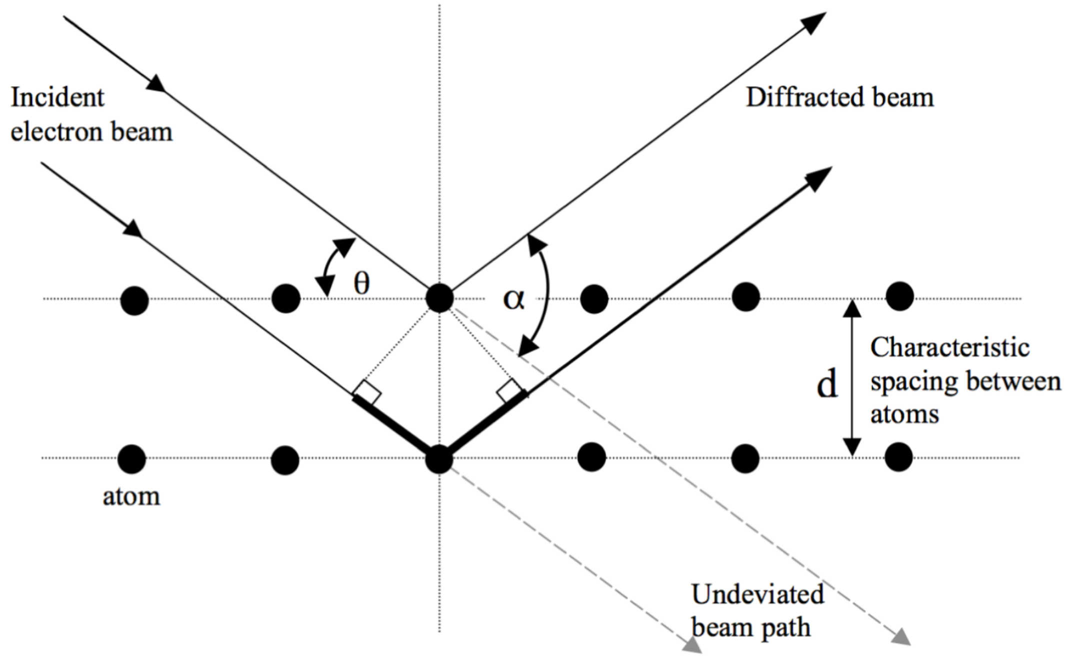


Figure 2: Diffraction from so-called Bragg planes in a crystalline medium. The heavy solid line in the lower part of the beam path represents the additional path length Δs traveled by the electrons in that part of the beam.

For constructive interference to occur, the path-length difference Δs traveled by the electrons in one part of the beam relative to the electrons in another part of the beam must be equal to an integer number of de Broglie wavelengths, i.e. $\Delta s = n\lambda$. The graphite layers can be treated as a set of discrete layers as in the image above, which shows that the Δs is related to the spacing of atoms in the crystal lattice, d, and the angle of incidence of the electron beam with respect to the surface of the target, θ. This geometry yields Bragg's Law:

$$2d \sin\theta = n\lambda \tag{3}$$

θ may not be easy to measure (in this case, because the target is held at/near the center of a sealed, evacuated chamber), but for planar geometry it is simply related to the deflection angle α between the undeviated beam path and the scattered electron path:

$$\theta = \frac{\alpha}{2} \tag{4}$$

α can be determined by measuring the linear diameter of a the diffraction ring projected onto a screen combined with knowledge of the dimensions of the TEL555 diffraction tube apparatus (see Procedure, below). Thus a measure of the diffraction ring diameter is tantamount to a measure of the electron wavelength.

Apparatus

The apparatus in this experiment in relatively simple; there are only three key components:

- "TEL-Atomic" 555 electron diffraction tube - more details given below and in the Appendix.
- 5 kV high voltage power supply
- Vernier calipers

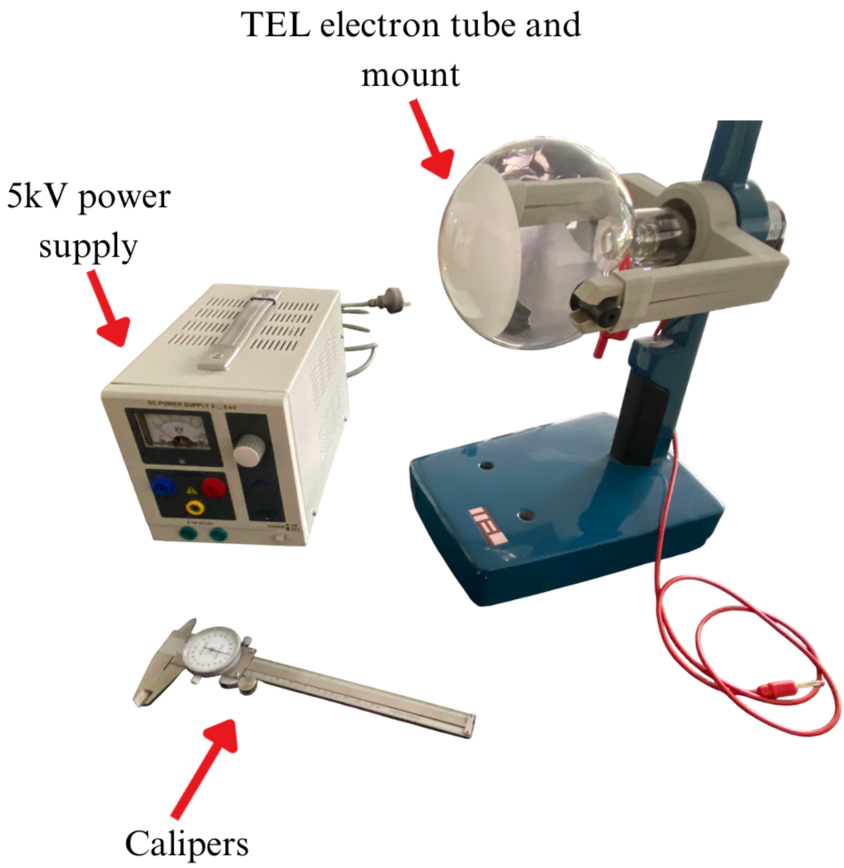


Figure 3: The apparatus used in this experiment.

The "TEL-Atomic" 555 electron diffraction tube

The electron tube used in this lab is an evacuated glass tube which generates a narrow, collimated beam of electrons from a heated cathode. These are directed through a layer of polycrystalline graphitized carbon (a powder) which acts as a diffraction grating, altering the path of the electrons. As a result, a diffraction pattern appears on the fluorescent screen as concentric rings, with an undeviated electron spot remaining at the center.

The geometry of the electrons path from the graphite sample to the screen is shown in Fig. 4 and some corresponding values are given in table 1.

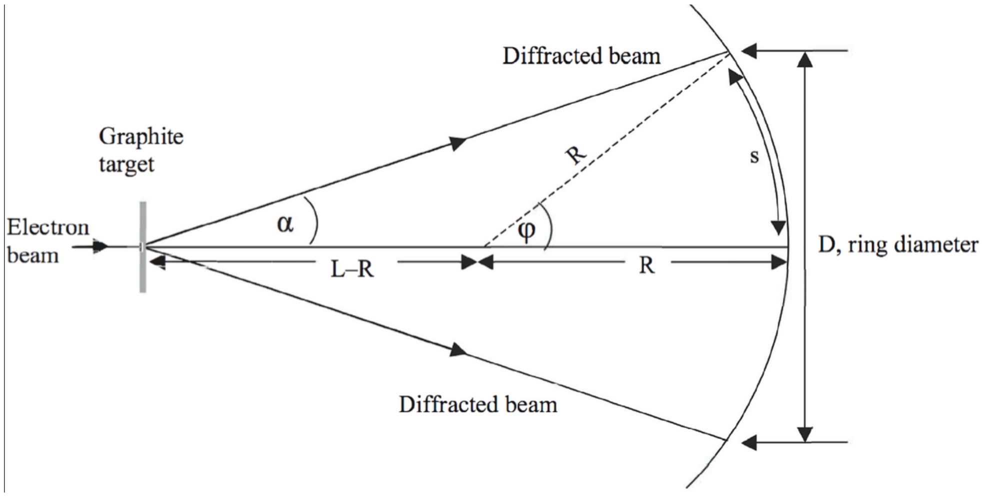


Figure 4: Geometry of the electron tube and graphite target. Note that $R \sin \varphi = D/2$.

Target-phosphor distance	L	125 ± 2mm
Screen radius	R	65.0 ± 0.5 mm
Glass tube thickness	t	1.50 ± 0.05 mm

Table 1: Dimensions of the TEL555 electron tube.

Further technical specifications of the electron diffraction tube are located in the appendix. This includes details on the components that make up the tube and how to connect it properly. Consult this prior to starting the experiment.

Procedure

With the apparatus described and the relevant physics discussed, it is now time to design and execute an experiment that achieves the Experiment Objectives.

Task

You have an apparatus capable of producing diffraction rings over a range of voltages. Create an experiment plan that allows you to determine the spacings of the carbon atoms in the graphite sample. When planning, it may help to think about the following questions?

1. Our guiding equation for this experiment is equation 2 which you derived in the pre-lab section of these notes. This will help us link our measurements to the atomic spacing of the graphite lattice. With this equation in mind, what sort of plot will you want to produce (what will you plot on the x and y axes)? What features of the plot will be beneficial to you?

2. Should you take multiple measurements of the rings at each voltage? If so, how many will you take and at what orientation?

3. Which parts of each ring should you measure?

4. How many voltages will you measure the ring diameters at?

Write down an outline of your experiment plan and discuss with your demonstrator before commencing.

While carrying out your experiment, remember to include the following in your logbooks:

1. Labeled diagrams of your setup.
2. Details of your process including processes which didn't end up working out.
3. Assumed values.
4. Sources of error.
5. Sanity checks to validate your initial observations and any preliminary results. In other words, how do you know you're on the right track before you get to your final results?

Calculations and Discussion

Some further work is required to accurately link your measurements of the ring diameters D_1 and D_2 to the diffraction angle α. This arises because the center of curvature of the electron tube is significantly offset from the position of the graphite target as shown in Fig. 4. The distance between the graphite target and the screen is L, but the radius of curvature of the screen is R.

In pre-lab exercise 4, you determined the equation for α from the geometry of the electron tube in Fig. 4. Because you have directly measured the diffraction ring diameters, D, the values in table 1 can be used to calculate the corresponding values of α which you will need to create a useful plot.

We can now evaluate de Broglie's hypothesis on the wave nature of electrons by comparing the derived values of α to the predictions from the de Broglie relation and the Bragg condition.

Task

1. What relationship between α and voltage do you expect based on your theoretical calculations?
2. From the plot you have created, what can you say about the wave nature of electrons based on your results?
3. Use your plot to determine the average atomic spacings in the target. Compare your results with the dimensions you found in prelab exercise 3. Comment on the accuracy of your results and your errors.
4. Use the ratio of D_2 to D_1 to learn the arrangement of the atoms in the crystal. Remember the ratios you determined in pre-lab exercise 5.
5. Why does the apparatus used here produce rings instead of bright spots perpendicular to the atomic separations?

As you process your results, remember to **propagate your errors and display error bars on key plots.**

References

Davisson, C. and L. H. Germer (Apr. 1927). “The Scattering of Electrons by a Single Crystal of Nickel”. In: *Nature* 119.2998, 558â560. ISSN: 1476-4687. DOI: 10.1038/119558a0. URL: http://dx.doi.org/10.1038/119558a0.

Appendices

Letters to the Editor.

[*The Editor does not hold himself responsible for opinions expressed by his correspondents. Neither can he undertake to return, nor to correspond with the writers of, rejected manuscripts intended for this or any other part of* NATURE. *No notice is taken of anonymous communications.*]

The Scattering of Electrons by a Single Crystal of Nickel.

IN a series of experiments now in progress, we are directing a narrow beam of electrons normally against a target cut from a single crystal of nickel, and are measuring the intensity of scattering (number of electrons per unit solid angle with speeds near that of the bombarding electrons) in various directions in front of the target. The experimental arrangement is such that the intensity of scattering can be measured

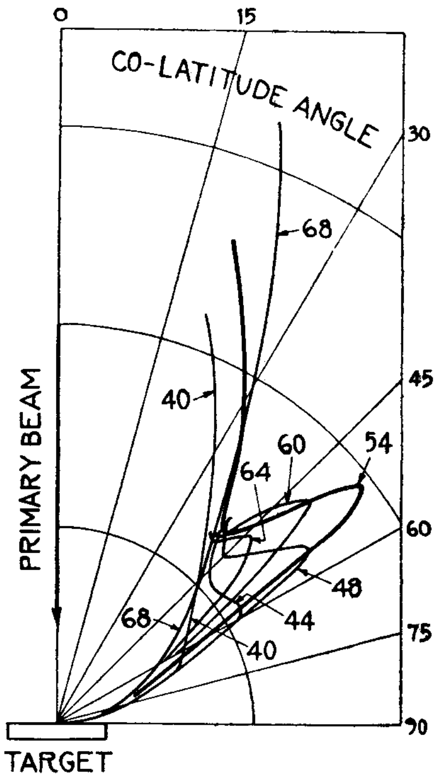


FIG. 1.—Intensity of electron scattering vs. co-latitude angle for various bombarding voltages—azimuth-{111}-330°.

in any latitude from the equator (plane of the target) to within 20° of the pole (incident beam) and in any azimuth.

The face of the target is cut parallel to a set of {111}-planes of the crystal lattice, and etching by vaporisation has been employed to develop its surface into {111}-facets. The bombardment covers an area of about 2 mm.^{2} and is normal to these facets.

As viewed along the incident beam the arrangement of atoms in the crystal exhibits a threefold symmetry. Three {100}-normals equally spaced in azimuth emerge from the crystal in latitude 35°, and, midway in azimuth between these, three {111}-normals emerge in latitude 20°. It will be convenient to refer to the azimuth of any one of the {100}-normals as a {100}-azimuth, and to that of any one of the {111}-normals as a {111}-azimuth. A third set of azimuths must also be specified; this bisects the dihedral angle between adjacent {100}- and {111}-azimuths and includes a {110}-normal lying in the plane of the target. There are six such azimuths, and any one of these will be referred to as a {110}-azimuth. It follows from considerations of symmetry that if the intensity of scattering exhibits a dependence upon azimuth as we pass from a {100}-azimuth to the next adjacent {111}-azimuth (60°), the same dependence must be exhibited in the reverse order as we continue on through 60° to the next following {100}-azimuth. Dependence on azimuth must be an even function of period $2\pi/3$.

In general, if bombarding potential and azimuth are fixed and exploration is made in latitude, nothing very striking is observed. The intensity of scattering increases continuously and regularly from zero in the plane of the target to a highest value in co-latitude 20°, the limit of observations. If bombarding potential and co-latitude are fixed and exploration is made in azimuth, a variation in the intensity of scattering of the type to be expected is always observed, but in general this variation is slight, amounting in some cases to not more than a few per cent. of the average intensity. This is the nature of the scattering for bombarding potentials in the range from 15 volts to near 40 volts.

At 40 volts a slight hump appears near 60° in the co-latitude curve for azimuth-{111}. This hump develops rapidly with increasing voltage into a strong spur, at the same time moving slowly upward toward the incident beam. It attains a maximum intensity in co-latitude 50° for a bombarding potential of 54 volts, then decreases in intensity, and disappears in co-latitude 45° at about 66 volts. The growth and decay of this spur are traced in Fig. 1.

A section in azimuth through this spur at its maximum (Fig. 2—Azimuth-330°) shows that it is sharp in azimuth as well as in latitude, and that it forms one of a set of three such spurs, as was to be expected. The width of these spurs both in latitude and in azimuth is almost completely accounted for by the low resolving power of the measuring device. *The spurs are due to beams of scattered electrons which are nearly if not quite as well defined as the primary beam.* The minor peaks occurring in the {100}-azimuth are sections of a similar set of spurs that attains its maximum development in co-latitude 44° for a bombarding potential of 65 volts.

Thirteen sets of beams similar to the one just described have been discovered in an exploration in the principal azimuths covering a voltage range from 15 volts to 200 volts. The data for these are set down on the left in Table I. (columns 1-4). Small corrections have been applied to the observed co-latitude angles to allow for the variation with angle of the 'background scattering,' and for a small angular displacement of the normal to the facets from the incident beam.

If the incident electron beam were replaced by a beam of monochromatic X-rays of adjustable wave-length, very similar phenomena would, of course, be observed. At particular values of wave-length, sets of three or of six diffraction beams would emerge from the incident side of the target. On the right in Table I. (columns 5, 6 and 7) are set down data for the ten sets of X-ray beams of longest wave-length which would occur within the angular range of our observations. Each of these first ten occurs in one of our three principal azimuths.

Several points of correlation will be noted between the two sets of data. Two points of difference will also be noted; the co-latitude angles of the electron beams are not those of the X-ray beams, and the three electron beams listed at the end of the Table appear to have no X-ray analogues.

The first of these differences is systematic and may be summarised quantitatively in a simple manner. If the crystal were contracted in the direction of the incident beam by a factor 0·7, the X-ray beams would be shifted to the smaller co-latitude angles θ' (column 8), and would then agree in position fairly well with the observed electron beams—the average difference being 1·7°. Associated in this way there is a set of electron beams for each of the first ten sets of X-ray beams occurring in the range of observations, the *electron* beams for 110 volts alone being unaccounted for.

These results are highly suggestive, of course, of the ideas underlying the theory of wave mechanics, and we naturally inquire if the wave-length of the X-ray beam which we thus associate with a beam of electrons is in fact the h/mv of L. de Broglie. The comparison may be made, as it happens, without assuming a particular correspondence between X-ray and electron beams, and without use of the contraction factor. Quite independently of this factor, the wave-lengths of all possible X-ray beams satisfy the optical grating formula $n\lambda = d \sin \theta$, where d is the distance between lines or rows of atoms in the surface of the crystal—these lines being normal to the azimuth plane of the beam considered. For azimuths-{111} and -{100}, $d = 2{\cdot}15 \times 10^{-8}$ cm. and for azimuth-{110}, $d = 1{\cdot}24 \times 10^{-8}$ cm. We apply this formula to the electron beams without regard to the conditions which determine their distribution in co-latitude angle. The correlation obtained by this procedure between wave-length and electron speed v is set down in the last three columns of Table I.

In considering the computed values of $n(\lambda mv/h)$, listed in the last column, we should perhaps disregard those for the 110-volt beams at the bottom of the Table, as we have had reason already to regard these beams as in some way anomalous. The values for the other beams do, indeed, show a strong bias toward small integers, quite in agreement with the type of phenomenon suggested by the theory of wave mechanics. These integers, one and two, occur just as predicted upon the basis of the correlation between electron beams and X-ray beams obtained by use of

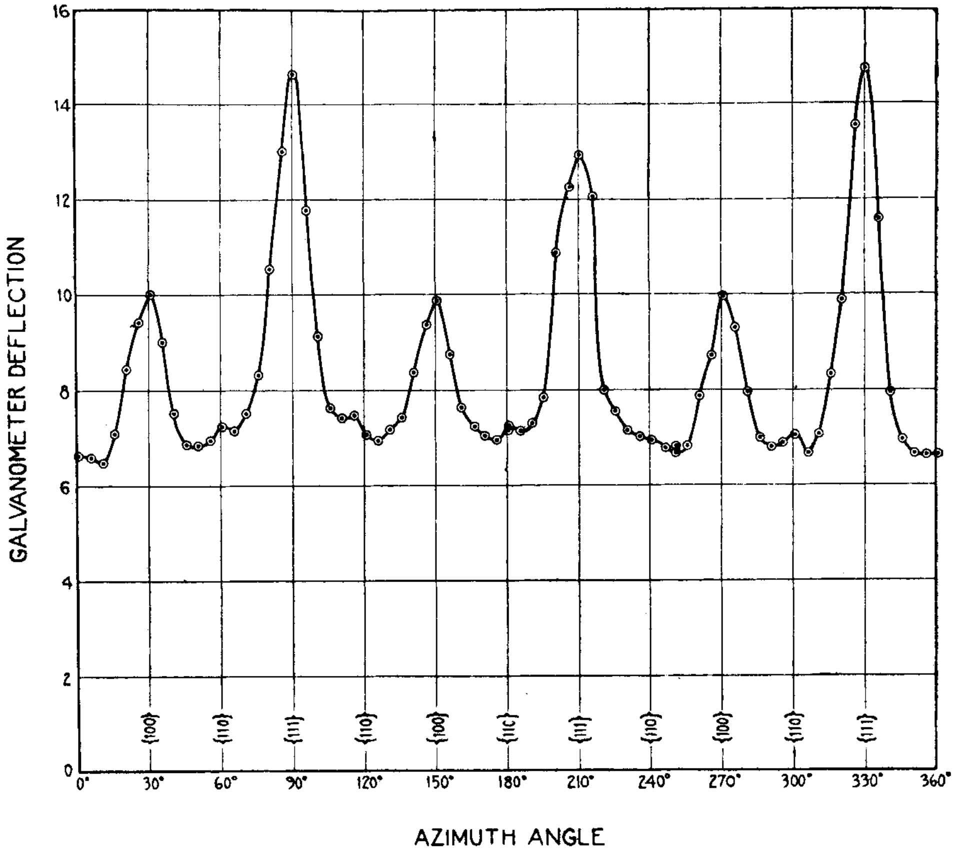


FIG. 2.—Intensity of electron scattering vs. azimuth angle—54 volts, co-latitude 50°.

TABLE I.

Azimuth.	Electron Beams.			X-ray Beams.						
	Bomb. Pot (volts).	Co-lat. θ.	Intensity.	Reflections.	$\lambda \times 10^8$ cm.	Co-lat. θ.	Co-lat. θ'.	$v \times 10^{-8}$ cm./sec.	$n\lambda \times 10^8$ cm.	$n\left\{\frac{\lambda mv}{h}\right\}$.
{111}	54	50°	0·5	{220}	2·03	70·5	52·7	4·36	1·65	0·99
	100	31	0·5	{331}	1·49	44·0	31·6	5·94	1·11	0·91
	174	21	0·9	{442}	1·13	31·6	22·4	7·84	0·77	0·83
	174	55	0·15	{440}	1·01	70·5	52·7	7·84	1·76	2(0·95)
{100}	65	44	0·5	{311}	1·84	59·0	43·2	4·79	1·49	0·98
	126	29	1·0	{422}	1·35	38·9	27·8	6·67	1·04	0·95
	190	20	1·0	{533}	1·04	28·8	20·4	8·19	0·74	0·83
	159	61	0·4	{511}	1·05	77·9	59·0	7·49	1·88	2(0·97)
{110}	138	59	0·07	{420}	1·22	78·5	59·5	6·98	1·06	1·02
	170	46	0·07	{531}	1·04	57·1	41·7	7·75	0·89	0·95
{111}	110	58	0·15	..	..	..	..	6·23	1·82	1·56
{100}	110	58	0·15	..	..	..	..	6·23	1·82	1·56
{110}	110	58	0·25	..	..	..	..	6·23	1·05	0·90

the contraction factor. The systematic character of the departures from integers may be significant. We believe, however, that this results from imperfect alignment of the incident beam, or from other structural deficiencies in the apparatus. The greatest departures are for beams lying near the limit of our co-latitude range. The data for these are the least trustworthy.

C. Davisson.
L. H. Germer.
Bell Telephone Laboratories, Inc.,
New York, N.Y.,
Mar. 3.

The Brain of Laplace.

The bicentenary of the death of Newton (March 20, 1727) is within a fortnight of the centenary of the death of Laplace (March 5, 1827), and no one acquainted with the work of both can think of one or other except in association. It may, therefore, not be an unfitting occasion to refer to an historical point with regard to the great Frenchman, when we are celebrating the great Englishman.

The physiologist and anatomist Magendie propounded the theory that the intelligence of a human being was in the inverse ratio of the amount of cerebrospinal fluid contained in the brain case. Writing in 1827, the year of Laplace's death, his "Mémoire physiologique sur le cerveau," [1] he inserted the following words:

> "Je me suis trouvé dans la douloureuse nécessité d'examiner le cerveau d'un homme de génie mort dans un âge avancé, mais jouissant encore de la plénitude de ses facultés intellectuelles; la somme totale du liquide céphalo-spinal ne s'élevait pas à deux onces, et les cavités du cerveau en contenaient à peine un gros" [$=\frac{1}{8}$ once].

I have been unable so far to find any further reference in the writings of Magendie "to the brain of this man of genius who died at an advanced age" and in the fullness of his intellectual powers. Magendie appears to have given no further account of this brain; at least I have found none. Laplace died at the age of seventy-eight in the year Magendie wrote. I have also failed to discover any minute record of Laplace's death which would suggest that an autopsy was made or was a "douloureuse nécessité." I would venture, therefore, to ask those who may be better acquainted than I am with the circumstances of Laplace's death to let me know why his brain came into Magendie's possession and whether a full report on it was ever written. Magendie, indeed, mentions no name, and this might lead one to consider his investigation of the matter was confidential. However, I think the ascription is certain, for quite recently Miss Helen Hunter Baillie—a lady who combines the blood of other famous anatomists with that of a famous author,[2] placed in the hands of Miss Miriam Tildesley a letter of Joanna Baillie to her great niece Miss Sophy Milligan. This letter, dated Hampstead, Monday, 1834, contains the following important paragraph:

> "My dear Sophy. . . . Dr. Somerville told us not long ago a whimsical circumstance regarding the head of La Place, the famous French astronomer. Some Ladies and Gentlemen went one day to the house of Majendie (sic!), the great anatomist, to see the brains of this Philosopher which they conjectured must be of a very ample size, and seeing a preparation on the table answering their expectation they were quite delighted. 'Ah! see what a superb brain, what organs, what developments! This accounts completely for all the astonishing power of his intellect, etc.' Majendie, who was behind them and overheard all this, stepped quietly forward and said: 'Yes, that is indeed a large brain, but it belonged to a poor Idiot, who when alive scarcely knew his right hand from his left. This, Ladies and Gentlemen' (handing to them a preparation of a remarkably small brain), 'this is the brain of La Place.' Dr. Somerville was told this anecdote by Majendie himself. . . .
>
> Your affectionate Aunt, J. Baillie."

This Dr. Somerville can scarcely be other than the physician, fellow of the Royal Society, and husband of Mary Somerville, the learned lady who studied Newton's "Principia" in the original, was the correspondent of Laplace, and paraphrased his "Mécanique Celeste." There can thus be no doubt that Magendie was in possession of the brain of Laplace, and very little doubt that the passage in the "Mémoire physiologique sur le cerveau," written 1827, refers to that brain. The questions I would put to the French readers of Nature are these: What became of Magendie's preparations? Have they, and with them Laplace's brain, survived until to-day? If so; has any one reported on it, or does any account by Magendie other than that I have cited, written or printed, exist? So few brains of great thinkers have been available for examination, that it would be a real disaster if Laplace's should have had only four lines devoted to it.

Karl Pearson.
Galton Laboratory,
University College, London,
Mar. 31.

[1] Published by Magendie in his own *Journal de Physiologie expérimentale et pathologique*, Tome 8, p. 228; 1828.

[2] The mother of Joanna Baillie was sister of William and John Hunter.

The Microscopical Examination of Flint Surfaces.

During the course of my work in the experimental fracture of flint by (*a*) human blows delivered by a hammer-stone, (*b*) unguided percussion, (*c*) unguided pressure, and (*d*) the application of heat, it became, in my opinion, possible, by a close examination of an extensive series of each of the differing types of flaking produced by these various methods of fracture, to differentiate between the work of man, and that of Nature ("Pre-Palæolithic Man," W. E. Harrison, publisher, Ipswich). While engaged upon this research I was much interested to notice that not only the type of flaking of the different series served to distinguish them from each other, but also that this difference appeared to find support, though in a less obtrusive manner, *in the appearance of the surface of the flints* broken by the methods above enumerated.

Most of those who are familiar with fractured flints of prehistoric date will have probably noticed the marked differences, often observable to the naked eye, between, for example, specimens broken by thermal effects and others fractured by human blows. The surfaces of the flake-scars of the former exhibit, generally, a much duller, less bright, surface than those of the latter. It occurred to me that this difference was caused possibly by the fact that these surfaces differed in texture, and had thus offered a differing resistance to the natural force, or forces, responsible for the imposition of 'polish,' or 'gloss,'' upon the flake-scars of fractured flints. Further, it seemed highly probable that this difference in texture, if it existed, would have been most likely to have been produced by the two differing forms of fracture, and I compared, provisionally, the surfaces of a flint broken by thermal effects, to those of an apple which has been pulled in half with the hands and exhibits a rough surface, while I likened the surfaces of the

3B SCIENTIFIC® PHYSICS

Electron Diffraction Tube D   1013885

Instruction sheet

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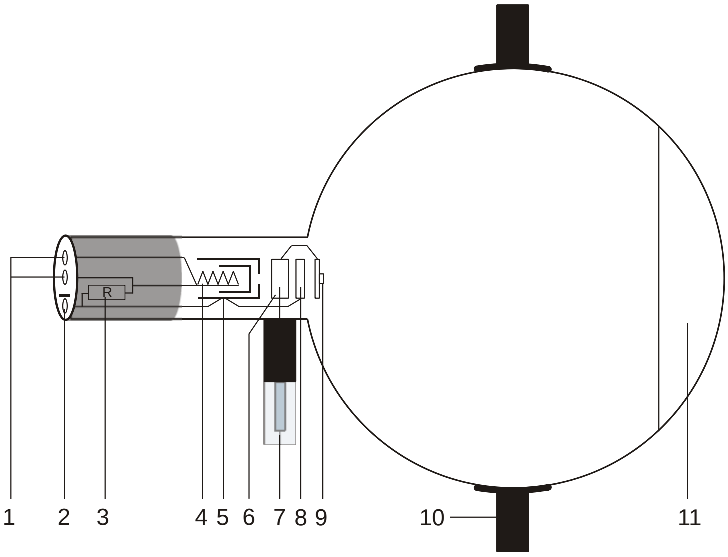

1. 4-mm sockets for connecting heater supply
2. 2-mm socket for connecting cathode
3. Internal resistor
4. Filament
5. Cathode
6. Anode
7. 4-mm plug for connecting anode
8. Focussing electrode
9. Polycrystalline graphite grating
10. Boss
11. Fluorescent screen

1. Safety instructions

Hot cathode tubes are thin-walled, highly evacuated glass tubes. Treat them carefully as there is a risk of implosion.

- Do not subject the tube to mechanical stresses.
- Do not subject the connection leads to any tension.
- The tube may only be used with tube holder D (1008507).

If voltage or current is too high or the cathode is at the wrong temperature, it can lead to the tube becoming destroyed.

- Do not exceed the stated operating parameters.
- Only change circuit with power supply equipment switched off.
- Only exchange tubes with power supply equipment switched off.

When the tube is in operation, the stock of the tube may get hot.

- If necessary, allow the tube to cool before dismantling.

The compliance with the EC directive on electromagnetic compatibility is only guaranteed when using the recommended power supplies.

2. Description

The electron diffraction tube illustrates the wave nature of electrons by allowing observation of interference caused by a beam of electrons passing through a polycrystalline graphite target on a fluorescent screen (Debye-Scherrer diffraction). The wavelength of the electrons can be calculated for various anode voltages from the radius of the diffracted rings and the distance between the crystal layers in the graphite. The tube also confirms the de Broglie hypothesis.

The electron diffraction tube is a highly evacuated tube with an electron gun consisting of a pure tungsten heater filament and a cylindrical anode all contained in a clear glass bulb. The electrons emitted by the heated cathode are constrained to a narrow beam by an aperture and are then focussed by means of an electron-optical system. The resulting tight, monochromatic beam then passes through a micro-mesh nickel grating situated at the aperture of the gun. Onto this grid, a thin layer of polycrystalline graphitised carbon has been deposited by vaporisation. This layer affects the electrons in the beam much like a diffraction grating. The result of this diffraction is seen in the form of an image comprising two concentric rings that become visible on the fluorescent screen. A spot resulting from the undeflected electron beam continues to be visible at the centre of the rings.

A magnet is also supplied with the tube. This allows the direction of the electron beam to be changed, which may be necessary if the graphite target has slight damage as a result of the manufacturing process or due to later overheating.

3. Technical data

Filament voltage:	≤ 7,0 V AC/DC
Anode voltage:	0 – 5000 V DC
Anode current:	typ. 0,15 mA at 4000 V DC
Lattice constant of graphite:	d_{10} = 0,213 nm d_{11} = 0,123 nm

Dimensions:

Distance graphite target / fluorescent screen:	125 ± 2 mm approx.
Fluorescent screen:	100 mm dia. approx.
Glass bulb:	130 mm dia. approx.
Total length:	260 mm approx.

4. Operation

Included in delivery:

1 adapter 2-mm with 4mm socket; it is required if the protective adapter, 3-pole (1009960) is not used to connect the cathode to the 2mm socket [(2) in diagram]. Via a safety experiment lead, the connection to the high-voltage power supply unit is realized in this way.

Additionally required:

To perform experiments using the electron diffraction tube, the following equipment is also required:

1 Tube holder D	1008507
1 High voltage power supply 5 kV (115 V, 50/60 Hz)	1003309
or	
1 High voltage power supply 5 kV (230 V, 50/60 Hz)	1003310
2 Pair of Experiment Leads, 75 cm	1002850
1 Experiment Lead, Plug and Socket	1002838

Additionally recommended:

1 Protective Adapter, 3-Pole	1009960
2 Pair of Safety Experiment Leads, 75 cm	1002849
1 Experiment Lead, Safety Plug/Socket	1002839

4.1 Setting up the tube in the tube holder

- The tube should not be mounted or removed unless all power supplies are disconnected.
- Push the jaw clamp sliders on the stanchion of the tube holder right back so that the jaws open.
- Push the bosses of the tube into the jaws.
- Push the jaw clamps forward on the stanchions to secure the tube within the jaws.
- If necessary plug the protective adapter onto the connector sockets for the tube.

4.2 Removing tube from the tube holder

- To remove the tube, push the jaw clamps right back again and take the tube out of the jaws.

4.3 General instructions

The graphite foil on the diffraction grating is only a few layers of molecules thick and any current greater 0.2 mA can cause its destruction.

The internal resistor is there to prevent damage to the graphite foil.

The graphite target itself should be monitored throughout the experiment. If the graphite target starts to glow, the anode must immediately be disconnected from its power supply

If the diffraction rings are not satisfactorily visible, the electron beam can be redirected by a magnet so that it passes through an undamaged region of the target.

5. Example experiment

- Set u the experiment as in Fig. 2. Connect the negative pole of the anode supply via the 2-mm socket.
- Apply the heater voltage and wait about 1 minute for the heater temperature to achieve thermal stability
- Apply an anode voltage of 4 kV.
- Determine the diameter *D* of the diffraction rings.

Two diffraction rings appear on the fluorescent screen centred on the undeflected beam in the middle. The two rings correspond to Bragg reflections from atoms in the layers of the graphite crystal lattice.

Changing the anode voltage causes the rings to change in diameter. Reducing the voltage makes the rings wider. This supports de Broglie's postulate that the wavelength increases as momentum is reduced.

a) Bragg equation: $\lambda = 2 \cdot d \cdot \sin\vartheta$

λ = wavelength of the electrones
ϑ = glancing angle of the diffraction ring
d = lattice plane spacing in graphite
L = distance between sample and screen
D = diameter D of the diffraction ring
R = radius of the diffraction ring

$$\tan 2\vartheta = \frac{D}{2 \cdot L} \qquad \lambda = d \cdot \frac{R}{L}$$

b) de-Broglie equation: $\lambda = \frac{h}{p}$

h = Planck’s constant
p = momentum of the electrones

$$e \cdot U = \frac{p^2}{2 \cdot m} \qquad \lambda = \frac{h}{\sqrt{2 \cdot m \cdot e \cdot U}}$$

m = electron mas, e = electron charge

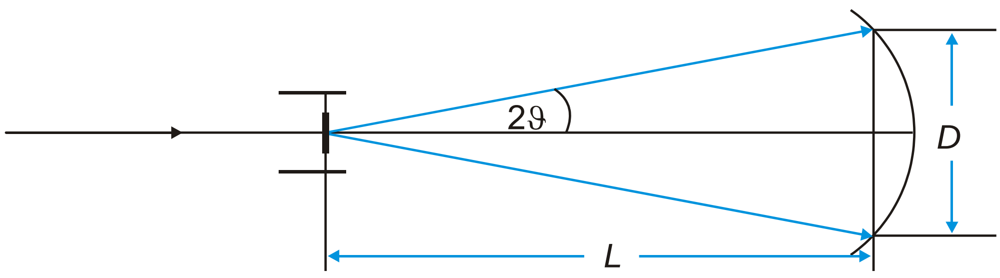

Fig. 1 Schematic representation to Debye-Scherrer diffraction

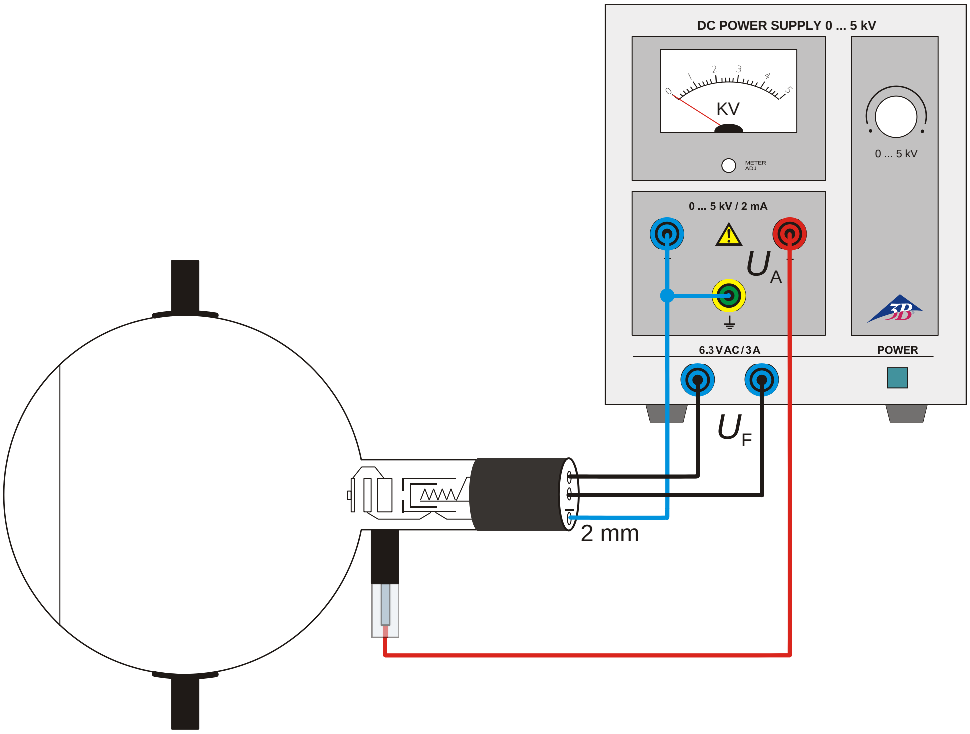

Fig. 2 Circuit of the diffraction tube D

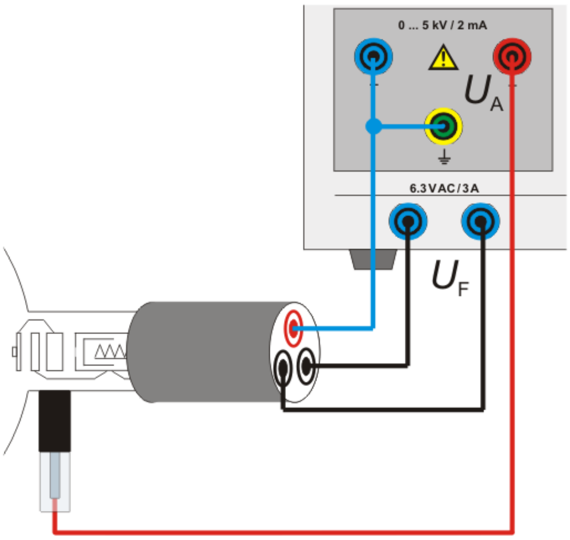

Fig. 3 Circuit of the diffraction tube D with protective adapter, 3-pole (1009960)