THE ELECTRON DIFFRACTION TUBE 2555

THE ELECTRON DIFFRACTION TUBE, TEL.2555, comprises a 'gun' which emits a narrow converging beam of electrons within an evacuated clear glass bulb on the surface of which is deposited a luminescent screen. Across the exit aperture of the 'gun' lies a micro-mesh nickel grid onto which has been vapourised a thin layer of graphitised carbon; the beam penetrates through this carbon 'target' to become diffracted into two rings corresponding to separations of the carbon atoms of 0.123 and 0.213 nanometers. The source of the beam of electrons is an indirectly-heated oxide-coated cathode.

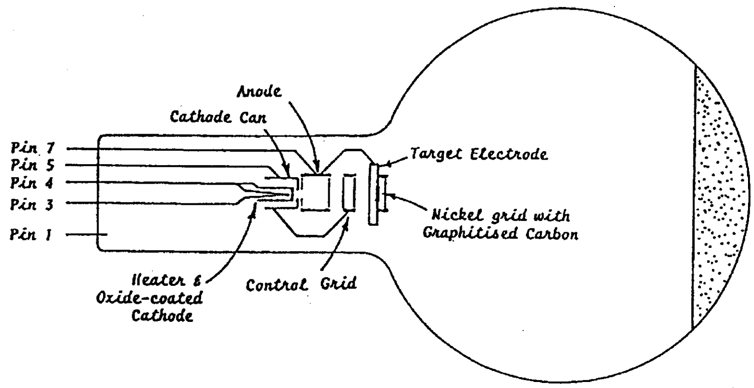


FIGURE 01 : SCHEMATIC OF THE ELECTRON DIFFRACTION TUBE, TEL.2555

Specification:

FILAMENT VOLTAGE	(V_F)	...	5 - 7 V dc max., see Notes , page 6.
ANODE VOLTAGE	(V_A)	...	2500 - 5000 V dc
ANODE CURRENT	(I_A)	...	0.15 mA at 4000 V (0.20 mA max.)

The tube is mounted in the UNIVERSAL STAND, TEL.2501.

Recommended Experiments:

Experiments with the Maltese Cross Tube, TEL.2523, demonstrate that cathode rays exhibit some properties that seem similar to those of light and other properties that appear to be consistent with those of electrically charged particles. It was suggested by Louis de Broglie in 1926 that particles could have wave properties where the wavelength, λ is inversely proportional to momentum, M ($= mv$).

The Teltron Series 'A' Experiments confirm that electrons obey the laws of motion and lead to a measure of the specific charge e/m. The Millikan experiment establishes the discrete nature of the electron, gives a measure of charge e and thereby an evaluation of its mass m. Sufficient information is thus available to test the de Broglie hypothesis.

The possibility of diffraction:

A calculation using de Broglie's equation shows that electrons accelerated through a p.d. of 4 kV have a wavelength of about 0.02 nanometers. Interference and diffracion effects, as studied in physical optics, demonstrate the existence of waves, where for a simple ruled grating, the condition for diffraction is

$$\lambda = d \sin \theta$$

where d is the spacing of the grating and where for small angles $\sin \theta = \theta$

The best man-made gratings are ruled at 2,000 lines per mm and with a wavelength of 0.02 nm, the angle θ will be less than one second of arc or only 0.5 mm at 10 m from the grating. If electron diffraction is to be observed in Teltron tube with a pathlength of 130 mm, the spacing between 'rulings' to produce a first order of interference at 13 mm from zero (i.e $\sin \theta = 0.1$), must be 0.2 nm.

In 1912, Prof. Max von Laue had suggested, in connection with X-ray studies, that if fine gratings could not be made by man because of the basic granularity of matter, then perhaps this very granularity might provide a suitable grating. Sir Lawrence Bragg used the cubic system of NaCl to calculate interatomic spacings and showed them to be of the right order for X-rays. This salt, like most salts, is not suitable for sealing into an evacuated tube; however Carbon is vacuum stable and can be formed in many different ways.

The graphitised carbon targets:

TIME - 5 mins	V_A, I_A, V_F - TEL.2813

A similar calculation can be made using Carbon and assuming that its atomic system is also cubic; 12 gms of Carbon contain 6×10^{23} atoms (Avogradro's Number); the density of Carbon is about 2 gms/cm^3, 1 cm^3 contains 10^{23} atoms so that adjacent Carbon atoms will be about $\sqrt[3]{10}$ or a little over 0.2 nm apart. It is thus reasonable to expect that Carbon should provide a grating of suitable spacing for an experiment.

The nature of the effect to be observed however is not evident from these calculations; before proceeding with the electron diffraction experiment it is recommended that students are prepared for the probable results by observing an Optical Analogue such as TEL.555A.

Connect tube TEL.2555 into the circuit of FIGURE 02.

Switch on the heater supply and wait about one minute for the oxide cathode to achieve thermal stability.

Slowly increase V_A.

Hold a standard laboratory magnet in the region of the 'electron gun' and observe the magnified pattern of the nickel grid with the graphitised carbon entrapped in a random manner.

The 'electron gun' behaves like a very simple electron microscope to magnify the target by about a factor of 30 times.

Use the 'crescent magnet' to 'roam' around the junction between the neck of the tube and the bulb and observe the improved clarity as the magnet deflects the convergent beam to scan the target grid.

EXPERIMENT A.23 : DEMONSTRATION OF ELECTRON DIFFRACTION.

TIME - 40 mins	V_A, I_A, V_F - TEL.2813	V_B - TEL.2811 *optional*

Connect the tube TEL.2555 into the circuit show in FIGURE 02, switch on the heater supply and wait one minute for the cathode to heat stabilise.

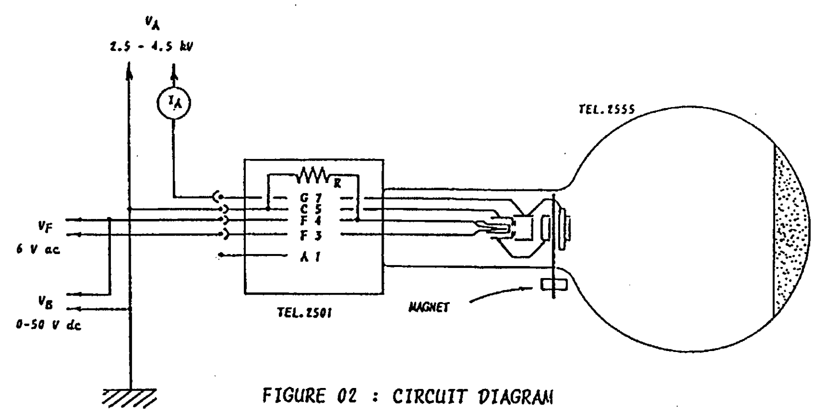


FIGURE 02 : CIRCUIT DIAGRAM

23.01 Adjust V_A to 4.0 kV. - **see Notes , page 6.**

Two prominent rings about a central spot are observed, the radius of the inner ring being in fair agreement with the calculated value of 13 mm. Variation of the anode voltage causes a change in diameter, decrease in voltage resulting in an increase in diameter. This is in accord with de Broglie's suggestion that wavelength increases with decrease in momentum. Evidence of the particulate nature of the electron has been previously obtained and so this demonstration, which so closely resembles the optical one, reveals the dual nature of the electron.

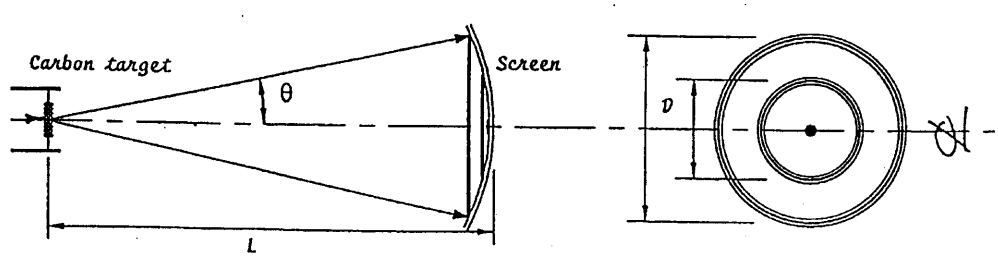


FIGURE 03 : THE RING PATTERN

The de Broglie wavelength of a material particle is

$$\lambda = \frac{h}{m v} \qquad 23.01$$

where h is Planck's Constant.

The law of conservation of energy requires that the change of kinetic energy plus the change of electrical potential energy of a charge traversing from point 1 to 2 must equate to zero because no work is done by external forces.

$$(\tfrac{1}{2} m v_2^2 - \tfrac{1}{2} m v_1^2) + (e V_2 - e V_1) = 0$$

Applied to an electron traversing the gun of the TEL.2555 tube $(V_2 - V_1)$ is V_A , $v_1 = 0$ and so , for negative charges

$$e V_A = \tfrac{1}{2} m v^2$$

Substitute for v in 23.01 to obtain

$$\lambda = \frac{h}{\sqrt{2 e m V_A}} = 1.23\, V_A^{-\frac{1}{2}} \quad nm \qquad 23.02$$

The condition for diffraction for small angles is

$$\lambda = d . \theta$$

where the small angle θ can be calculated from the geometrical relationship shown in FIGURE 03 as

$$\theta = \frac{D/2}{L}$$

and so from 23.02

$$D . \frac{d}{2L} = 1.23\, V_A^{-\frac{1}{2}} \qquad 23.03$$

and

$$D = k\, V_A^{-\frac{1}{2}} \qquad 23.04$$

23.02 Using a caliper drawing instrument measure the diameters D for different anode voltages V_A ; tabulate and plot the graph.

V_A	$V_A^{-\frac{1}{2}}$	D metres	
kV	volts $^{-\frac{1}{2}}$	inner	outer
2.5	0.0200		
3.0	0.0183		
3.5	0.0169		
4.0	0.0158		
4.5	0.0149		

TABLE 01

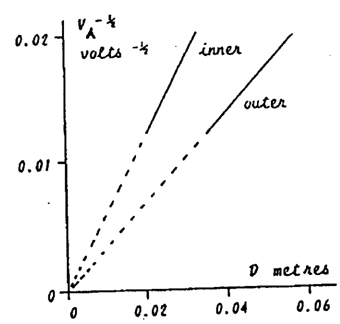


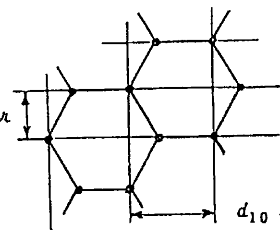
FIGURE 04

The convention of proportionality has been inverted for the purposes of this graphical construction in order to facilitate the calculations of d_{10} and d_{11} from the gradients of the respective lines.

23.03 Measure the pathlength from the Carbon target at the gun exit aperture to the luminescent screen , L m , as accurately as possible using a back-reflection technique; this may be difficult to achieve due to image distortion caused by the change in the geometry of the glass envelope; the length is controlled during production to be 0.130 ± 0.002 m to yield an accuracy of better than 2 % .

23.04 Rearrange the equation *23.03* so as to evaluate the interatomic spacings d using the gradients of the graphs of the outer and inner circles; compare with the established figures of d_{11} (0.123) and d_{10} (0.213) nm .

Note that the ratio of the spacings is $\sqrt{3}:1$ which suggests that the Carbon atoms are more likely to be arranged in hexagonal rather than the assumed cubic pattern.



CONCLUSIONS

These results verify the theory and substantiate the de Broglie hypothesis.

Clinton Davisson and Lester Germer first demonstrated the diffraction of electrons by glancing off a crystalline Nickel target in 1927 and G.P.Thomson (the son of J.J.Thomson who developed the Balanced Fields e/m experiment, see TEL.2525) published the first results of this type of transmission diffraction in 1928; he used targets of gold, aluminium, silver and platinum but the energy required for the electrons was between 15 kV and 60 kV; at voltages higher than 5 kV the thickness of the glass envelope of apparatus like the TEL.2555 tube may be insufficient to absorb the X-rays scattered by the impact of high-energy electrons upon the targets and such experiments are not permitted in the normal school or university experimental laboratory.

The de Broglie wavelength is so small that it is only possible to produce observable diffraction effects for electrons and other elementary particles. In 1930 O.Stern and I.Esterman succeeded in demonstrating the diffraction of a stream of Hydrogen molecules and in 1931 they diffracted Helium atoms using a Lithium Fluoride crystal.

In all cases the de Broglie hypothesis holds true and from it quantum relationships were developed by Erwin Schrodinger and others.

Owing to their small penetrating power electrons are diffracted mainly in the surface layers and electron diffraction is used extensively as a means of studying surface conditions.

QUALITY OF RESULTS

The accuracy of the calculations of atomic spacing depends on the length of the gradient line of FIGURE 05 and the caliper measurement of the ring diameters.

Length of gradient line:

The length can be extended in the direction of the origin by using lower voltages and operating in a darkened room, focussing using V_G to sharpen the pattern and making due allowance for the influence of the glass envelope.

Measurement of ring diameters:

For maximum accuracy the ring diameter should be extrapolated as in FIGURE 05 in order to compensate for both the curvature and the thickness of the glass envelope; the lower the anode voltage, the larger the ring diameter and the greater the percentage influence of these parameters.

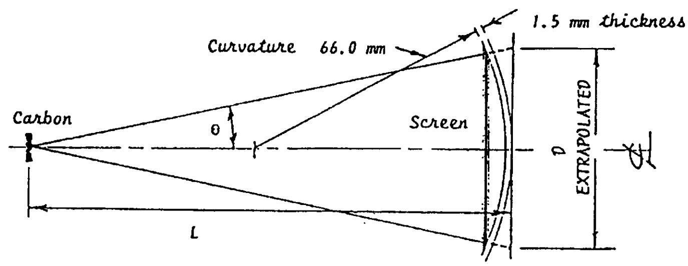


FIGURE 05 : ALLOWING FOR GLASS ENVELOPE

NOTES

1.0 Protection of the carbon target:

The graphitised Carbon through which the electron beam is confined to pass is only a few molecular layers in thickness and can be punctured by current overload. The 33K Resistor, *R* is incorporated into the Filament Protection Circuit of the UNIVERSAL STAND, TEL.2501 to provide 'negative auto-bias' and so reduce the liklihood of damage to the target due to accidental user-abuse. The total emitted current passes through the resistor *R* ; increase in current causes the cathode-can to become more negatively biassed, so reducing the emitted current.

2.0 Practical precautions:

Current overload causes the target to become overheated and to glow dull red; it is good practise to inspect the target periodically during an experiment and especially at switch-on when at least one minute should be allowed for the cathode temperature to stabilise before applying anode voltage.

As an additional safeguard, the anode current should be metered and never allowed to exceed 0.2 mA; external meters should be capable of operating at high voltage; the TELTRON KILOVOLT power supplies TEL.1813 and TEL.2813 have built in insulated metering facilities.

3.0 Magnetic tuning and external biassing:

The effects of the magnet and of the voltage V_B may vary according to gun construction and the thickness of the graphite target; either or both should be removed during Experiment A.23 if found to not produce meaningful results.

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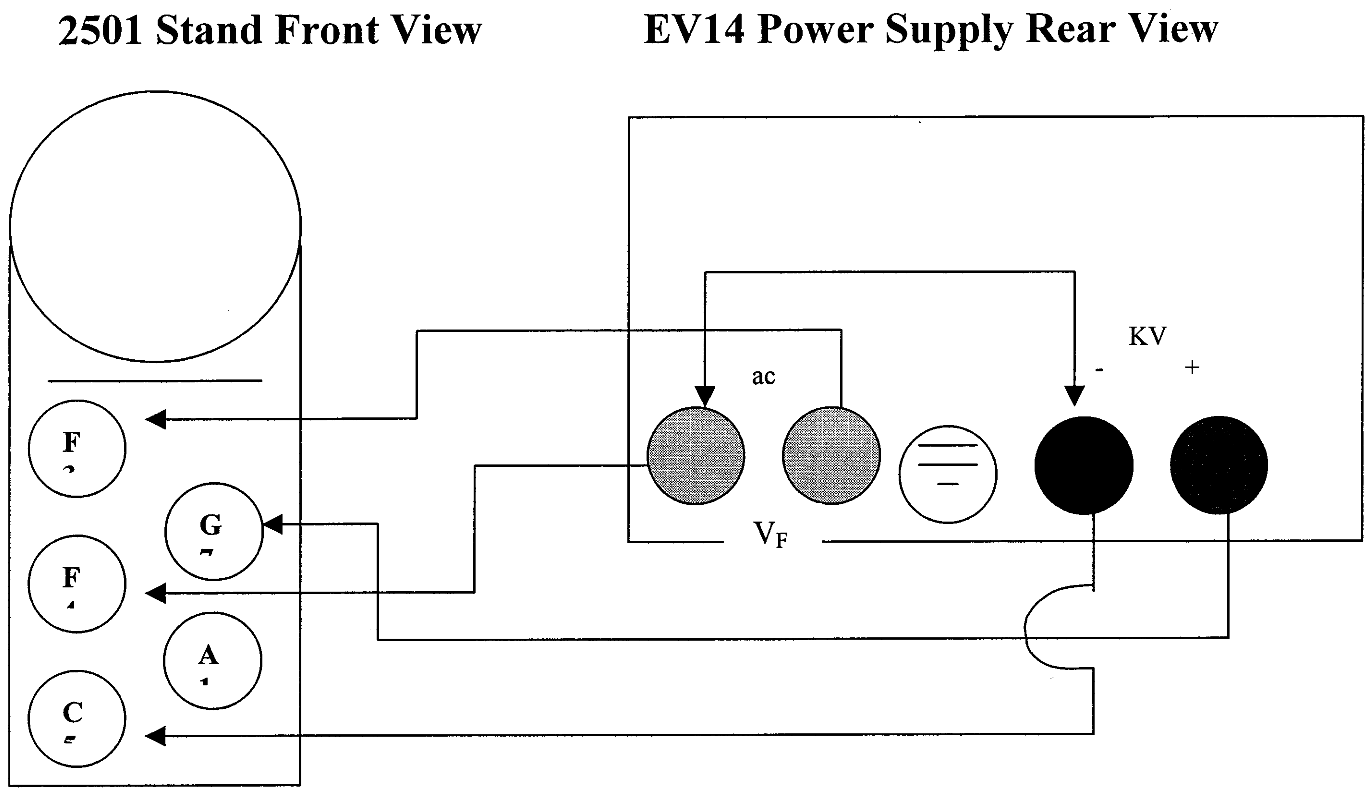

Wiring diagram for the TEL-2555 Electron Diffraction Tube