

# Electron Diffraction

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## 1. Introduction

In this experiment you will explore the wave-particle duality. You will do so by observing electron diffraction. The goal will be to test de Broglie's hypothesis that states that all particles have wave properties and the momentum and the wave-length are related through the Planck's constant:

$$\lambda = h/p \quad (1)$$

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

$$\lambda = d \sin \theta \quad (2)$$

or for small angles:

$$\theta = \lambda / d \quad (3)$$

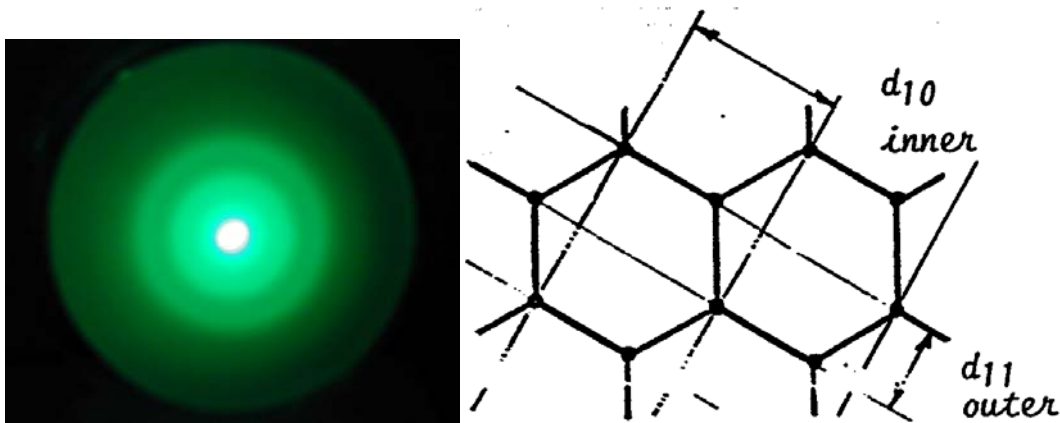
where  $d$  is the spacing of the grating. The best man-made gratings are ruled at 40,000 lines/inch and with a wavelength of 0.02 nm,  $\theta$  will be one second of arc. Thus, the deflection of the electron beam will be only  $\sim 0.3$  mm at 10 m from the grating. If electron diffraction is to be observed in a Teletron tube of  $\sim 14$  cm diameter then the wavelength must be of the order 0.2 nm. How can we make such a grating?

It was von Laue who suggested, in connection with x-ray studies, that if fine gratings could not be made by man because of the structure of matter, then perhaps the structure of matter itself could be used as a grating. Bragg, using the cubic system of NaCl, first calculated the interatomic spacings and showed them to be of the right order for x-rays. A similar calculation using carbon assuming that its atoms form a simple cubic system, can be made, viz: 12 gms of carbon contain  $6 \times 10^{23}$  atoms (Avogadro's No.); since the density of carbon is about 2 gm/cm<sup>3</sup>, 1 cm<sup>3</sup> contains  $10^{23}$  atoms so that adjacent carbon atoms will be about  $\sqrt[3]{10}$  or a little over 0.2 A apart. So carbon should provide a grating at the correct spacing for the experiment and that is what the manufacturers put inside the apparatus.

## 2. Apparatus

Teletron 555 Electron Diffraction tube  
Teletron 501 Universal Stand  
Filament and Accelerating voltage Power Supply  
External Bias Power supply  
Digital multimeters  
High-current , low resistance rheostat  
Calipers

We will perform this experiment using an electron diffraction tube TEL.555. It 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 micromesh nickel grid onto which has been vaporized a thin layer of graphitized carbon. The beam penetrates through this carbon target to become diffracted into two rings, as shown below:



**Figure 1** (left) Electron diffraction from a carbon foil. The bright spot in the middle is the non-deflected beam. The two bright rings correspond to the 1<sup>st</sup> maximum for two different atomic spacings in the hexagonal lattice of carbon ( shown on the right figure)  $d_{11}= 0.123$  nm and  $d_{10}= 0.213$  nm.

The wiring diagram of the Teletron 555 is shown in Figure 2. There are three circuits that need to be connected: filament heater supplying  $V_F$ , accelerating potential  $V_A$ , which accelerate the electrons emitted from the heated cathode to the carbon target. The external bias ( 0-50 V) focuses the electron beam and allows for the diffraction pattern to be visible at lower accelerating potential. You will adjust the external bias voltage to obtain an optimal result.

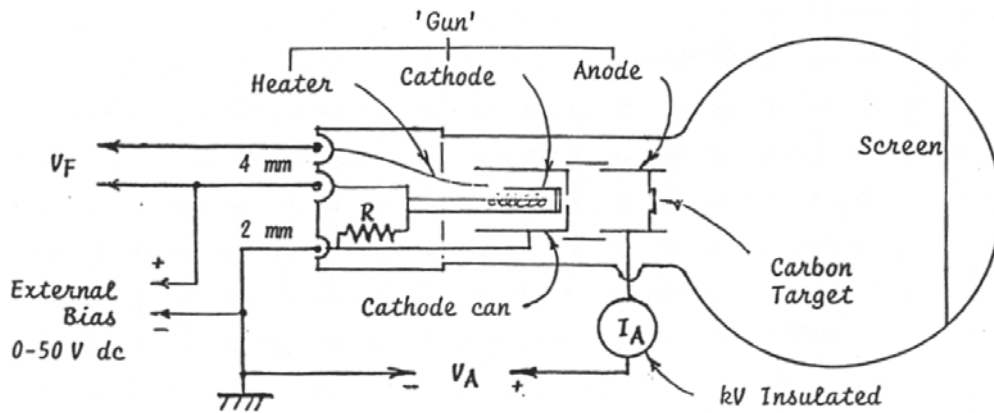


Figure 2 Wiring diagram for the Teletron 555 electron diffraction tube. The filament current should not exceed 0.2 mA!

The electrical specifications of the apparatus are given below:

Filament voltage Normal 6.3 V a.c. / d.c. ; max. 9.0V a.c. / d.c.

Anode voltage 3,500 – 5,000V d.c

Anode current 0.2 – 0.4 mA

**Caution: The manufacturer recommends that the anode current does not exceed 0.2 mA during the operation of the tube. Operating at higher anode currents will cause over-heating and possibly burning a hole into of the carbon target which is just several atomic layers thick !** In order to assure safe operating conditions: 1) you should connect an ammeter in the anode circuit and monitor the anode current. **(ALWAYS connect ammeters in series with the voltage source, or the meter will be damaged.)**

2) You can achieve lower anode currents by lowering the current in the filament circuit. A high-current low-resistance rheostat should be connected in the filament circuit. The correct value of the rheostat is ~ 20 Ohm.

### 3. Procedure

To enable the observation of the electron diffraction rings, the experiment will be performed in a darkened room (one of the back rooms in this lab).

**CAUTION: You will use exposed voltages as high as 5000 kV. The voltage will need to be adjusted in a dimly lighted room. Make sure that you take all precautions to perform the measurement safely!**

1. When you walk into the room you will find that the circuit diagram from Figure 2 is already set-up. Without turning any of the power supplies on, you need to verify the connections and to make sure that you understand the correspondence between the diagram in the figure and what you see in the set-up.
2. Now, that you understand the set-up, sit down and think about what you will be measuring. Using the 'gun' equation:

$$eV_a = \frac{1}{2}mv^2 \quad (4)$$

the de Broigle equation (1) write an expression for the electron wavelength as a function of the accelerating voltage  $V_a$ . This expression should contain several known constants, the wavelength and  $V_a$ .

On the next step: using the condition for the 1<sup>st</sup> interference maximum (2), or better – the small angle approximation (3), write an expression that will connect the electron wavelength to something that you can measure ( the ring diameter D).

Finally, derive the following expression for the ring diameter as a function of the accelerating voltage:

$$D = \frac{2L}{d} \frac{h}{\sqrt{2me}} \frac{1}{\sqrt{V_a}} \quad (5)$$

Here d is the diffraction grating spacing,  $L= 0.140 \pm 0.003$  m is the distance from the carbon target to the luminescent screen ( as measured by the manufacturer), h is Planck's constant, m and e are the mass and the charge of the electron.

Looking at this expression you find that the diameter of the ring is proportional to  $V_a^{-1/2}$ . Your goal is to confirm this relation with your measurement. Then using this expression and your data you can determine Planck's constant, if you know the parameters of the lattice that you are using as a grating or you can measure the lattice spacing, if you know Planck's constant.

3. Call your instructor. Have her check the circuit and show her your derivation.
4. Turn on the power supply providing the filament heating and the acceleration potential. Wait about 1 min for the filament to be heated before applying accelerating potential.
5. Turn on the bias voltage power supply.
6. Apply  $V_a = 2.5$  kV and darken the room. **Have a flashlight handy and do not put your hands near the exposed HV wires in the dark!** Two rings should be visible now. You may want to adjust the bias voltage to get a sharper image.
7. Measure the diameters of the two rings for  $V_a = 2.5 - 5$  kV in steps of 0.5 kV  
The rings have finite thickness. Which size (inner side, outer side, middle) should you record?

#### 4. Data analysis and report

Tabulate your data of  $D$  and  $V_a$ . Plot  $D$  vs  $V_a^{-1/2}$ . Do your data points have a linear relation? Fit a straight line through the points. Determine the slope and its error (Excel will give you the error if you do Tools/ Data analysis/Regression).

1. Assuming that you know the atomic spacing (given in Section 2) determine Planck's constant and its error. Does your result agree with the accepted value?
2. Assuming that you know Planck's constant (use the accepted value) determine the lattice spacing for  $d_{10}$  and  $d_{11}$ . Does your result agree with the accepted values for carbon?
3. Do you need to consider relativistic effects in this experiment? In eqn (5), how much is  $D$  affected by the relativistic change in the mass at the highest acceleration voltage?
4. Make sure to include the derivation of eqn. 5 in your report.

#### 5. References:

Users Guide: Electron Diffraction Tube 555, Tel-Atomics