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## Operating instructions

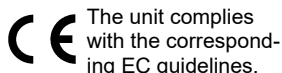


Fig. 1: 06959-00 Narrow-beam tube 06959-00 in pair of Helmholtz coils 06960-00

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### 1 SAFETY PRECAUTIONS



#### Caution!

- Carefully read these operating instructions before operating this instrument. This is necessary to avoid damage to it, as well as for user-safety.
- Do not start up this instrument in case of visible signs of damage to it.
- Only use the instrument for the purpose for which it was designed.

- It should be avoided to place the experimental setup near a magnetic field.

### 2 PURPOSE AND CHARACTERISTICS

The narrow beam tube 06950-00 is used in conjunction with the pair of Helmholtz coils 06960-00 to study the behaviour of an electron beam in a magnetic field normal to the electron trajectory, which is made visible by the fluorescence of the insert gas with which the tube is filled. The tube has an axial scale shaped like a ladder, whose metal 'rungs' are given a coat of luminous paint to enable the diameter of the electron trajectory to be measured accurately in order to determine the specific charge  $e/m$  of an electron. After evacuation, the tube is filled with neon at a pressure of about  $4 \times 10^{-3}$  mbar. This residual pressure of inert gas plays an important role in the focusing of the electron beam. Along their trajectory the electrons collide with gas molecules and ionise them, so that the beam is made visible by the luminescence produced by the recombination of the neon. Since, on the other hand, only the secondary ions arising escape from the beam during ionisation, the sluggish positive neon ions form a thread along the path of the electron beam, which as a result of electrostatic forces of attraction makes an important contribution to the sharp focusing of the beam, even over large distances. Each of the similar Helmholtz coils is cantilevered off a plastic foot. The coils are positioned by three spacer rails so that their axial spacing is equal to the average coil radius. (The rails can be removed after undoing knurled screws; allowing the coils to be used individually). Two for these rails are provided with a clip holding the narrow-beam tube in the centre of the pair of coils. The sockets of the coil winding are cast into the plastic foot of the coil; and the connecting leads can be used to connect the coils in parallel or series as required. The sockets are numbered (1; 2) to make it easier to wire the coils.

Cantilevering the coils from the base allows the number of turns to be counted. The fact that the turns of the individual layers are slightly offset relative to one another (see Fig. 2) must be allowed for when counting. Each coil is wound from copper wire in 14 layers, each of 11 turns, giving the number of turns  $n = 154$ .

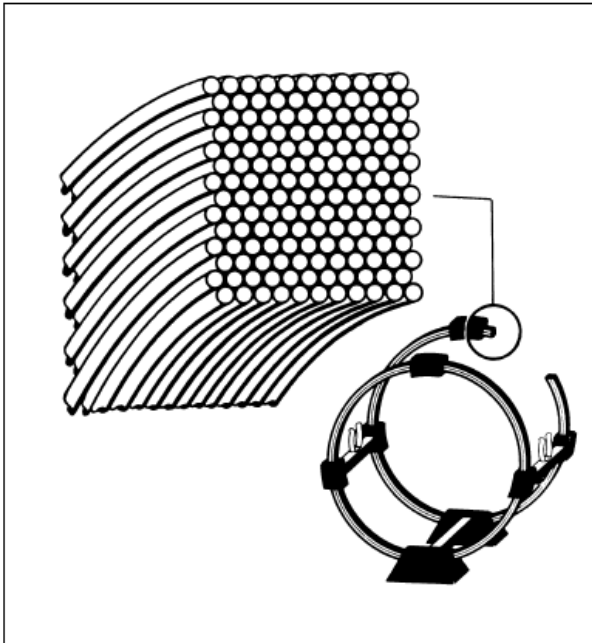


Fig. 2: Winding arrangement of the Helmholtz coils.

### 3 THEORY

#### 3.1 Determining the specific charge $e/m$

Electrons moved in a magnetic field are acted upon by a force normal to the field direction and normal to the direction of movement. The magnitude of the force is proportional to the charge  $e$  and the velocity  $v$  of the electrons as well as the magnetic flux density  $B$ . If the narrow-beam tube is arranged in the magnetic field of the Helmholtz coils so that the beam leaves the electron gun normal to the field direction, the force  $F$  acting on the electrons is given by:

$$F = e v B.$$

Under the influence of this force the beam is deformed into an arc of a circle, and bent into a complete circle of radius  $r$  when the magnetic field is sufficiently strong. The force  $F$  acting on the electrons must then equal the centrifugal force

$$e v B = \frac{m v^2}{r} \quad (1)$$

Transforming this equation gives the following relation for the velocity  $v$  of the electrons.

$$v = \frac{e}{m} B r \quad (2)$$

From the Law of Conservation of Energy  $1/2 m v^2 = e U$  it follows directly that the velocity of the electrons depends on the magnitude of the accelerating voltage  $U$ :

$$v = \sqrt{\frac{e}{m} \cdot 2U} \quad (3)$$

Substituting Eq. (3) in Eq. (2) gives the following expression for the specific charge of the electron

$$\frac{e}{m} = \frac{2U}{r^2 B^2} \quad (4)$$

Since all of the quantities on the right hand side of Eq. 4 can be determined by measurement, it is possible to calculate the specific charge of the electron.

#### 3.2 Determining the magnetic flux density at the centre of the Helmholtz coils

The Helmholtz-Gauguin arrangement for producing homogeneous magnetic fields is characterised by the fact that the same current will flow through two individual circular conductors of the same radius, whose centres lie on the common axis at a spacing equal to their radii. If instead of individual, circular conductors, coils with a large cross section are used, the deviations from homogeneity are small if certain restrictions on the cross of the coils are observed and the distance from coil centre to coil centre is chosen to equal the average coil radius. The magnetic flux density  $B$  inside such a Helmholtz coil system can be calculated from the average coil radius  $R$ , the number of turns  $n$  of a coil and the current  $I$  in the coils:

$$B = 0,715 \mu_0 \frac{n \cdot I}{R} \quad (5)$$

This presumes that the current  $I$  in both coils is identical.  $1.256 \cdot 10^{-6} \text{ T m/A}$  is to be taken as the value of  $\mu_0$ .



Fig. 3: Experimental setup for determining  $e/m$  with the narrow beam tube.

## 4 HANDLING

To start with, the two Helmholtz coils are connected with the aid of the matching spacer rails. The rails are secured by tightening the knurled screws; producing a stable configuration that holds the narrow-beam tube as shown in Fig. 3.

### 4.1 Electrical connection of the narrow-beam tube

All of the electrical supply voltages for the narrow-beam tube are taken from the mains adapter 13672-93. The sockets on the end of the tube are marked so that correct connection to the power supply should not present any problems. Fig. 4 shows the circuit for the setup shown in Fig. 3. The circuit of the narrow-beam tube described above selects a fixed filament voltage of 6.3 V~, whereas the grid voltage supplied to the electron gun and the anode voltage can be adjusted with the aid of the potentiometers fitted in the mains adapter from »-50...0 V« and »0...+300 V«. The velocity and hence the energy of the electrons of the narrow beam is given by the total accelerating voltage  $U$  acting between cathode and anode. It is measured with a 300 V~ moving-coil instrument.

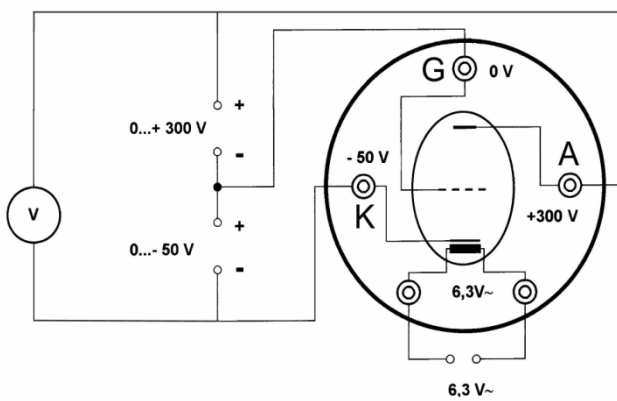


Fig. 4: Electrical circuit of the narrow beam tube.

### 4.2 Power supply to the Helmholtz coils

The two Helmholtz coils are connected in series, the polarity being chosen so that the fields of the coils add. This is achieved by, for instance, interconnecting the sockets marked »1« of the two coils and supplying the current through the two sockets marked »2«. The current is measured with a moving-coil instrument (3 A~) and allows calculation of the magnetic flux density as describe in Section 2.

Please make sure to operate the Helmholtz coils with a voltage regulated power supply that provides a smoothed output voltage.

The universal power supply 13500-93 is suitable for supplying the Helmholtz coils. However, if there is only a low-voltage DC supply available it may be advisable to connect the coils in parallel. To ensure that the currents in the two coils are approximately identical the ammeter should be connected into their common supply lead. Half the current reading shown is then to be used for calculating the field.

#### Note:

If the narrow beam is deflected only insignificantly or not at all when the power is switched on the fields of the two coils are cancelling each other out. This is remedied by reversing the supply leads to one of the coils!

### 4.3 Turning the narrow-beam tube on and determining the specific charge of the electron

Before the tube is turned on it must be ensured that the two potentiometers »50...0 V« and »0...300 V« of the mains adapter are on zero. This avoids voltage being present at the grid or anode of the electron gun when the filament voltage is switched on. This makes absolutely sure that the cathode layer cannot be damaged during heating.

Only after a heating time of about one minute are the two potentiometers turned up so that the presence of the narrow beam can be observed in a well darkened room. The level of the anode voltage is chosen with the »0...300 V« potentiometer, whereas with the aid of the »-50...0 V« potentiometer the grid voltage and hence the focus and brightness of the narrow beam can be suitably adjusted. The full intensity of the narrow beam is not generally achieved until heating has been continued for 2 to 3 minutes. When measurement is interrupted for quite some time it is advisable to turn the two potentiometers back to zero. This considerably extends the life of the narrow-beam tube.

The following experimental procedure can be adopted to determine the specific charge of an electron:

1. After the heating period the narrow beam is adjusted appropriately and a certain acceleration voltage  $U$  selected.
2. The current through the Helmholtz coils is then switched on and the circular path described by the narrow beam under the influence of the homogeneous magnetic field observed (max permissible continuous current 5 A).
3. The narrow-beam tube is turned in its clips to ensure that the beam leaves the electron gun exactly normal to the direction of the magnetic field and describes a full circle when the strength of the magnetic field is sufficient.
4. The coil current is set so that the narrow beam impinges on one of the four measuring rungs. A full circle with radii of 2, 3, 4 and 5 cm can be set up in this manner.
5. The coil current  $I$  required to produce a full circle of radius  $r$  at the accelerating voltage  $U$  indicated by the voltmeter is now read off the ammeter and the specific charge  $e/m$  of the electron (reference value:  $e/m = 1.759 \times 10^{11}$  as/kg) calculated by substitution these measured values in Eq. (4) and (5).

The accuracy with which the specific charge  $e/m$  of an electron is determined is largely governed by the measuring accuracy of the quadratic terms of Eq. (4), i.e. of radius  $r$  and magnetic flux density  $B$ . The radius  $r$  can be determined extremely accurately with the aid of the device fitted in the tube for measuring the diameter of the beam circle, so errors arising in this measurement can be kept small ( $< 1\%$ ). Since the magnetic flux density  $B$  is calculated from the coil current  $I$  using Eq. (5), the accuracy of the value determined for  $e/m$  is heavily dependent on the accuracy of this current measurement. When a high level of accuracy is required it is therefore strongly advisable to connect the Helmholtz coils in series, so that the same current flows through both of them.

## 5 TECHNICAL DATA

Narrow-beam tube	
Gas filling	Neon
Gas pressure	$4 \times 10^{-3}$ mbar
Cathode filament voltage	6.3 V
Cathode voltage	max -50 V
Grid voltage	0 V
Anode voltage	max +300 V
Diameter of the glass bulb	approx. 170 mm
Total length	47 cm
Pair of Helmholtz coils	
Coil diameter	400 mm
Number of turns per coil	154
Coil resistance	2.1 $\Omega$
Max current per coil (continuous load)	5 A
Max lux density at $I = 5$ A in Helmholtz configuration	3.5 mT

## 6 LIST OF EQUIPMENT

The following equipment is required for the experimental set-up shown in Fig. 3:

Narrow beam tube	06959-00
Pair of Helmholtz coils	06960-00
Power supply, universal	13500-93
Power supply 0...600 V-	13672-93

Measuring instruments:

Multimeter ADM 2, demo., analogue (2x)	13820-00
or	
Digital multimeter 2005 (2x)	07129-00
Connecting cords	

## 7 NOTES ON THE GUARANTEE

We guarantee the instrument supplied by us for a period of 24 months within the EU, or for 12 months outside of the EU. Excepted from the guarantee are damages that result from disregarding the Operating Instructions, from improper handling of the instrument or from natural wear.

The manufacturer can only be held responsible for the function and technical safety characteristics of the instrument, when maintenance, repairs and alterations to the instrument are only carried out by the manufacturer or by personnel who have been explicitly authorized by him to do so.

## 8 WASTE DISPOSAL

The packaging consists predominately of environmentally compatible materials that can be passed on for disposal by the local recycling service.



Should you no longer require this product, do not dispose of it with the household refuse.

Please return it to the address below for proper waste disposal.

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