Operating instructions
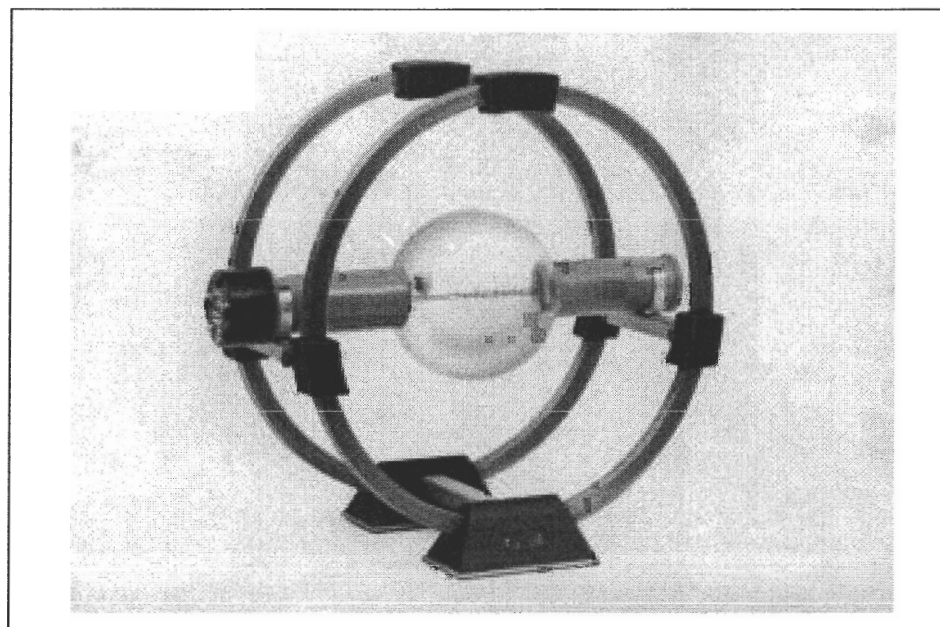

Fig. 1: Narrow-beam tube 06959.00 in pair of Helmholtz coils 60960.00

1. PURPOSE AND DESCRIPTION

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 argon at a pressure of about 10^{-1} Pa (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 argon. Since, on the other hand, only the secondary ions arising escape from the beam during ionisation, the sluggish positive argon 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 fo 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.
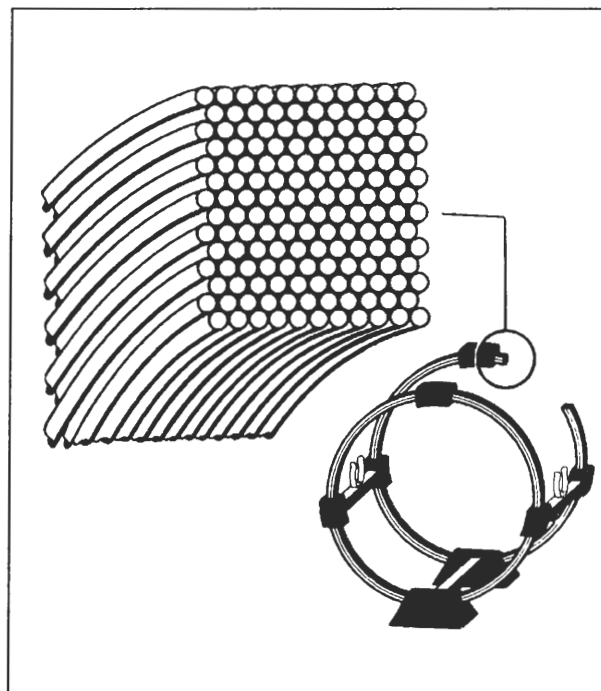

Fig. 2: Winding arrangement of the Helmholtz coils.

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 (sf 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 $n = 154$.

2. THEORY

2.1 Determining the specific charge e/m

Electrons moved in a magnetic field are acted upon by a foce normal to the field direction and normal to the direction of movement. The magnitude of the force is porportional to the charge e end 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 $\dfrac{mv^2}{r}$:

$$evB = \frac{mv^2}{r} \qquad (1)$$

Transforming this equation gives the following relationfor the velocity v of the electrons.

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

From the Law of Conservation of Energy $^1/_2 \, mv^2 = e \, U$ it follows directly that the velocity of the elctrons depends on the magnitude of the accelerating voltage U:

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

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

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

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

2.2 Determining the magnetic flux density at the centre of the Helmholtz coils

The Helmholtz-Gaugain 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 larger 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:

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

This presumes that the current I in both coils is identical. $1.256 \; 10^{-6}$ T m/A is to be taken as the value of μ_0.

3. SETTING UP

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 stabel configuration that holds the narrow-beam tube as shown in Fig. 3.

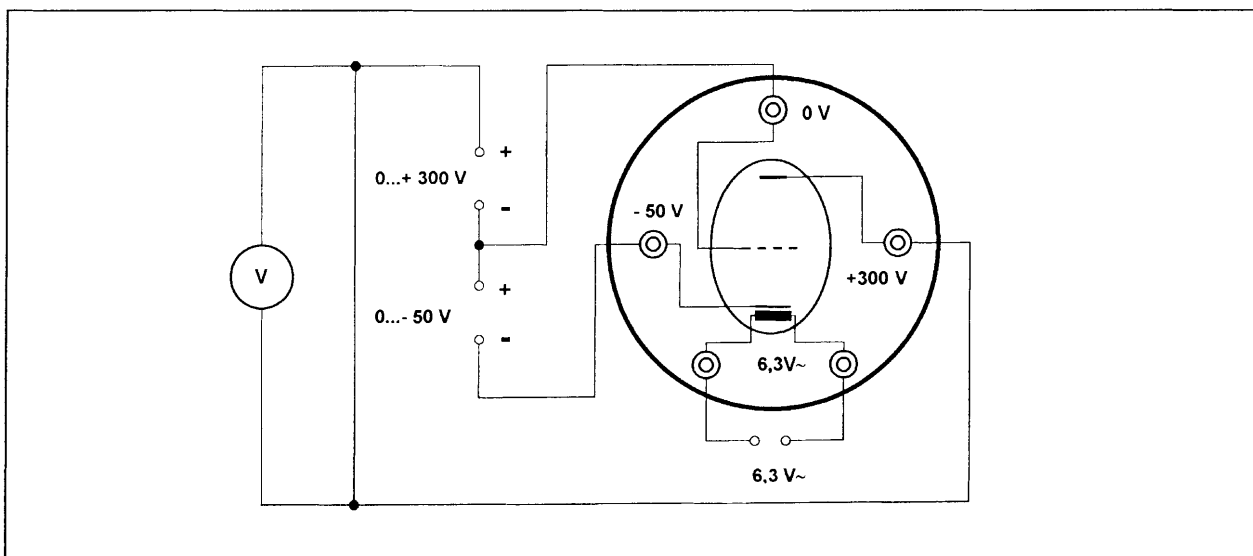Fig. 3: Experimental setup for determining e/m with the narrow-beam tube.
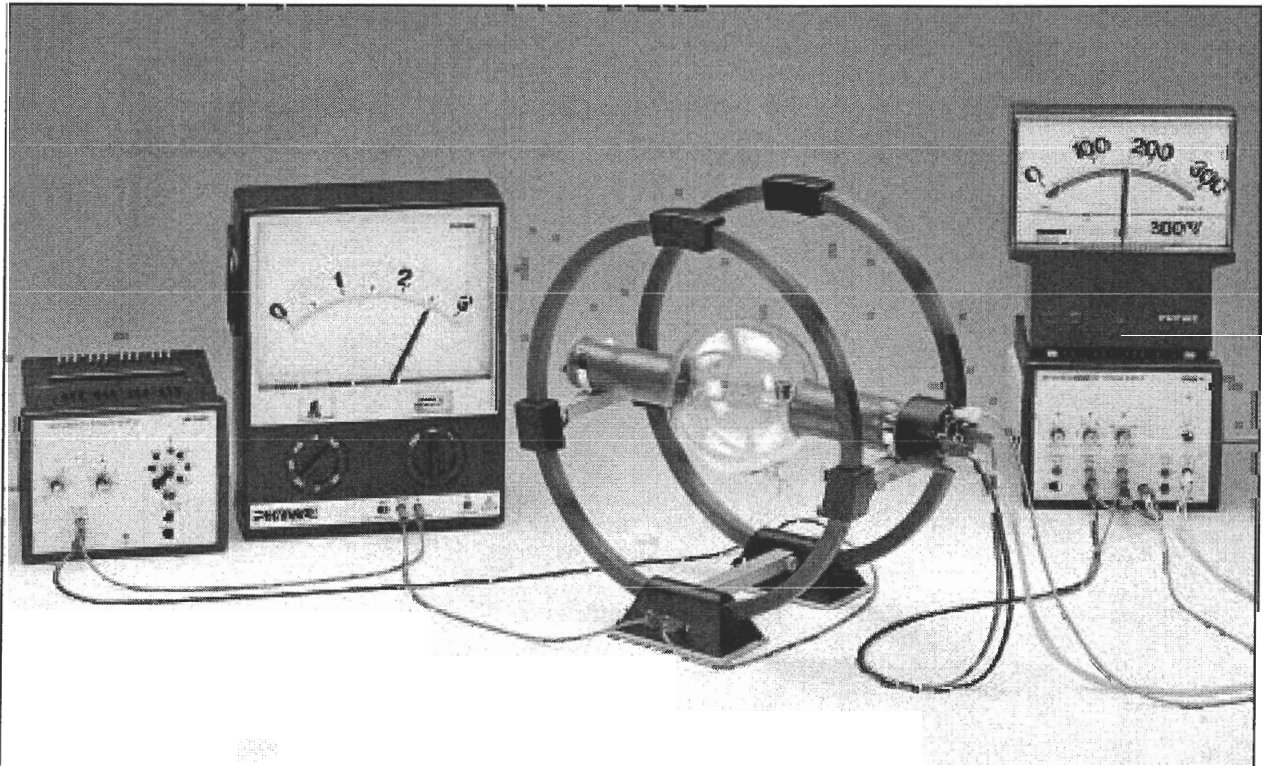
Fig. 4: Electrical circout of the narrow-beam tube.

3.1 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...+250 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.

3.2 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. Ths 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 ot the magnetic flux density as describe in Section 2.

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.

NB

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!

3.3 Turning the narrow-beam tube on an d 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...250 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 duringheating.

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...250 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 certein 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 elctron 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: $e/m = 1.759 \cdot 10^{11}$ 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), ie 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.

4. TECHNICAL DATA
Narrow-beam tube

Gas filling	argon
Gas pressure	10^{-1} Pa
Cathode filament voltage	6.3 V
Cahtode voltage	max −50 V
Grid voltage	0 V
Anode voltage	max +250 V
Diameter of the glass bulb	about 170 mm
Total length	47 cm

Pair of Helmholtz coils

Coil diameter	400 mm
Number of turns per coil	154
Coil resistance	2 . 1
Max current per coil (continuous load)	5 A
Max flux density at $I = 5$ A in Helmoltz configuration	3.5 mT

5. GUARANTEE
We guarantee equipment we supply for a period of 6 months; this does not cover normal wear and tear or defects caused by a lack of care.

The manufacturer can only be held responsible for proper operation and safety of the equipment if maintenance, repairs and modifications are carried out by him or his expressly authorised agents.

6. LIST OF EQUIPMENT
The following equipmnt is required for the experimental setup shown in Fig. 3:

narrow beam tube	06959.00
paor of Helmholtz coils	06960.00
power supply, universal	13500.93
regulated power suplly 0…600 V−	13672.93

Measuring instruments for demonstrative display:
Multimeter ADM 2, demonstration, analogue (2x)13820.00
or

moving coil instrument	(2x)11100.00
range multiplier 3 A−	11102.33
range multiplier 300 V−	11104.53
connecting cables	