Answer to question 25 (exam paper)

(a) Electrons are emitted by a hot filament at the cathode by thermionic emission, focused by a magnetic condensing lens (focusing coil) and accelerated toward the positive anode.
(b) Electric field E is applied at the deflecting plates (which should be labeled in the diagram). Downward E will produce upward accelerating force F = -qE, where q is the charge on the electron. This force will produce upward acceleration a = qE/m, where m is the mass of the electron. If it takes the electron time t to pass through the plates of width L, deflection $y = ½at^2$ and $L = v_x t$. (v_x is the horizontal velocity, with which the electron entered the plates). From those two equations y can be obtained as $y = (qEL^2)/2mv_x^2$. Once the electron leaves the deflecting plates, it will no longer be accelerated and the deflection at A can be computed from the dimensions of the tube.
(c) In a television set the electron beam is passed over the screen in a set pattern and its intensity is varied to produce a picture. Magnetic force $F= qv_x \times B$ is used to steer the beam along its path.

The ink-jet printing

Drops are negatively charged and travel parallel to the x-axis with constant velocity v_x. They will be accelerated upward: $a_y = (QE)/m$ in time t, while they fly through the plates. Deflection y = ½at2 and $L = v_x t$. Eliminating t, we obtain the deflection:

$$y = (QEL^2)/2mv_x^2$$

Some realistic numbers to substitute in this equation: $m = 1.3 \times 10^{-10}$ kg
$Q = 1.5 \times 10^{-13}$ C
$v_x = 18$ m/s
L = 1.6 cm
$E = 1.4 \times 10^6$ N/C

Simplifying assumptions: E is uniform, the weight of the drop is negligible compared to electrostatic force.

Milikan oil drop experiment (1910 – 1913)

Oil drop of radius R = 2.76 μm has an excess charge of 3e ($e = -1.6 \times 10^{-19}$ C). What are the magnitude and direction of electric field E required to keep the drop stationary? The density of oil $\rho = 920$ kg/m^3.

$$F_E = -F_G$$

To work out magnitude

$$3eE = 4/3\ \pi R^3 \rho g$$

g acceleration due to gravity = 9.8 m/s^2

$E = (4\pi R^3 \rho g)/9e = 1.65 \times 10^6$ N/C

We need an upward electrostatic force to balance downward gravitational force. As the charge is negative, E must point downward ($F_E = -eE$).

Thomson's e/m experiment (1897)

Experimental procedure was to set E and B to zero and note the position of the undeflected beam spot. Then apply a known electric field E (V/d) and not the beam deflection. Apply magnetic field B and adjust its value until the deflection is again 0.

For E only, the deflection y is:

$$y = (eEL^2)/2mv^2 \qquad (1)$$

L is the length of the plates, v is the electron speed. The direction of the deflection allows us to determine the sign of the particle charge.

To cancel the electrostatic deflection, $F_m = ev \times B$

$$eE = evB$$
$$v = E/B \qquad (2)$$

The crossed fields allow us to measure the speed of the particles passing through them. Combining equations (1) and (2) and rearranging:

$$e/m = (B^2L^2)/2yE$$