Appendices

Appendix A
A Simple Approach to the Concept of Capacitance

Consider two insulated conductors well separated from each other, one of which carries positive charge and the other negative charge of equal magnitude. The potential of the positively charged conductor (A) will be positive owing to the positive charges on it, and that of the negatively charged capacitor (B) will be negative due to the negative charges on it.

Now bring the two conductors close together; the potential of A \( V_A \) will be reduced owing to the nearby negative charges on B, and the potential of B \( V_B \) will be raised owing to the nearby positive charges on A. The potential difference \( V_A - V_B \) will therefore be reduced, and if the two conductors are very close to each other, it will require much larger amounts of charge to give \( V_A - V_B \) its original magnitude. Such a combination of conductors in close proximity is called a capacitor. The ratio \( Q/V \) of the magnitude of the charge on each to the potential difference (P.D.) between them is called the capacitance \( C \). Thus,

\[ C = \frac{Q}{V}. \]

The capacitance, \( C \), of a capacitor depends on the distance, \( d \), between its conductors and the area, \( A \), they present to each other. The functional relationship between \( C \) and \( A \) and \( d \) depends only on the geometrical shape and arrangement of the conductors, but the smaller \( d \) and the larger \( A \) are, the larger is \( C \). For the case of the very simple geometry of two parallel plates:

\[ C \propto \frac{1}{d} \quad \text{and} \quad C \propto A. \]

Charging a capacitor with a battery

Since \( V = Q/C \), if the capacitor is originally uncharged, the P.D. between its plates is zero.

Therefore,

\[ V_B = V_A, \]

and \( V_A \) is the same potential as that of the +ve terminal of the battery. The P.D. \( V_B - V_D \) across the resistance, \( R \), is therefore initially equal to the P.D. between the terminals of the battery, \( V \). A current, \( i \), given by:

\[ i = \frac{(V_B - V_D)}{R} = \frac{V}{R}, \]

therefore flows in the direction shown, and, as a result, charge begins to build up on the plates, +ve charge on A and -ve charge on B at a rate given by:

\[ \frac{dq}{dt} = i = \frac{(V_B - V_D)}{R} = \frac{V}{R}, \]

and the P.D. \( V_A - V_B \) starts to increase. Since \( V_A \) is fixed (at the potential of the +ve terminal of the battery), \( V_B \) must fall, and hence \( V_B - V_D \) must fall (as \( V_D \) is fixed at the potential of the -ve terminal of the battery). Hence,

\[ \frac{dq}{dt} = i = \frac{(V_B - V_D)}{R} \]

steadily reduces as the capacitor charges up. Eventually we reach a stage where \( V_B = V_D \) and \( i = 0 \): the P.D. between the plates of the capacitor is \( V \).
Appendix B  The Junction Diode

Semiconductors and Doping

Germanium and silicon are semiconductor materials commonly used for diodes and transistors. Both are elements of valence four; that is, in the crystalline state an atom is held by bonds formed by sharing its four valence electrons with four other atoms. At absolute zero all these bonds would be intact, but at room temperature a few will fracture due to thermal vibrations, and some electrons will be free to move throughout the crystal. The “hole”, or absence of electric charge, left by the electron also effectively moves. For example, if an electron in a neighbouring atom moves under the action of the electric field to fill the gap, then the hole will appear to have moved in the opposite direction as if positively charged. The energy required to produce such a “electron-hole” pair is 0.7 eV for germanium and 1.1 eV for silicon. Therefore, equal numbers of electrons and holes can act as negative and positive charge carriers, respectively, in the conductor.

If then the semiconductor is “doped”, that is, controlled amounts of a selected impurity are added, then the balance between the positive and negative mobile charge carriers can be upset and the conductivity of the semiconductor can increase dramatically. For example, if a small amount (say one part in $10^8$) of an element of valence five, e.g. phosphorus or arsenic, were added then the impurity atoms would try to fit into the semiconductor lattice. However, at each impurity site there would be one valence electron over, and at room temperature nearly all these weakly bound electrons would be free to move throughout the lattice. The conductivity would have increased by more than a factor of ten. The remaining impurity atom would be positively charged but it is not a free hole since it cannot accommodate any neighbouring free electrons. (All four bonds with the lattice are already filled.) This type of doped semiconductor is known as an $n$-type (for negative) semiconductor because the current is mostly carried by electrons, known as the “majority carriers”. The phosphorus or arsenic is called a donor impurity because it donates an electron to the conduction process.

Alternatively, one can form a $p$-type (for positive) semiconductor by adding an acceptor impurity, which would be an element of valence three, e.g. indium or aluminium. Its atoms would also try to fit into the semiconductor lattice but for each atom there would be one valence electron too few to form all four bonds. An electron from a neighbouring atom would be attracted to the impurity site. The result would be a hole where the electron came from which would be available for conduction, and a fixed, negatively-charged ionized acceptor atom at the impurity site. Therefore, holes are majority carriers in a $p$-type semiconductor.
The Junction Diode

A semiconductor junction diode is formed at the junction between a p-type and a n-type region in the same crystal. Initially, mobile electrons near the junction flow from the n-type region to the p-type region to combine with positively-charged holes there, and holes near the junction "move" in the opposite direction. This current will stop when a large enough potential barrier is formed across the junction - holes moving towards the n-type region will be repelled by the electric field created by an excess of positive charge there, and, similarly, electrons moving towards the p-type region will be repelled by the electric field set up due to the electrons which have already migrated there. The p-type region is left with an overall negative charge, and the n-type region is left with an overall positive charge. The net result is a P.D. across a region around the junction containing no mobile carriers - the "depletion region".

Now consider the effect of connecting an external P.D., for example a battery, across the diode.

If a battery is connected so as to increase the P.D., then no net number of majority carriers will be able to cross the junction and almost no current will flow. Only the small number of thermally released minority carriers (holes in the n-type region, electrons in the p-type region) will be able to cross the junction and form a current, which typically is microamps at most.

If a battery is connected with opposite polarity to that shown above, and the E.M.F. is gradually increased from zero, it will decrease and then reverse the internal P.D. across the diode. Majority carriers on either side would then be able to cross the junction and a relatively large current would be established. As the E.M.F. is increased, the resistance of the diode drops to near zero and the current increases rapidly.
Appendix C The Field Effect Transistor (n-type)

In Experiment 2 (Electronics) there is a discussion of why the drain current, \( I_D \), decreases as the gate bias \( V_{GS} \) becomes more negative.

\[
\begin{array}{c|c|c|c|c|c}
V_{DS} \text{ (Volts)} & 25 & 10 & 5 & 0 & \ldots \ldots \ldots \\
I_D \text{ (mA)} & & & & & \\
\hline
V_{GS} = 0.0 \text{ V} & & & & & \\
= -0.5 \text{ V} & & & & & \\
= -1.0 \text{ V} & & & & & \\
= -1.5 \text{ V} & & & & & \\
= -2.0 \text{ V} & & & & & \\
\end{array}
\]

In order to also explain the shape of a typical characteristic curve (where \( V_{GS} \) is fixed) we need to look at the bias across the pn junction in more detail.

Consider, firstly, the case where \( V_{GS} = 0 \). Then the gate is at the same potential as the source, and will define it as zero potential. However, the drain is at some positive potential, \( V_{DS} \), with respect to the source, and consequently, as electrons move from the source towards the drain, they move to higher and higher potential. As the gate is at zero potential, the potential difference across it is highest near the drain, and at its lowest value (but not zero) near the source. As a consequence, all parts of the pn junction are reversed biased even when \( V_{GS} \) is zero. The depletion region will be greatest where the reverse bias is greatest, i.e. near the drain, hence the asymmetric shape as drawn above. Even when \( V_{DS} \) is also zero, there is still a small depletion region due to the junction's own internal potential barrier (see Appendix B).

Now we increase \( V_{DS} \) from zero. At first, the semiconductor bar will just act as a resistor, and \( I_D \) will depend linearly on \( V_{DS} \). However, as \( V_{DS} \) is increased, the depletion region will spread out into the n-type semiconductor and to the greatest extent at the drain end. As the remaining channel for the current becomes very constricted, the current's rate of increase will slow and the characteristic curve will begin to "turn over". Eventually a situation is reached where the ohmic increase in current which would be normal for an increase in voltage is balanced by the reduction in current due to channel narrowing, and the net current is almost constant. This is called the "pinch-off" region of the characteristics.

If \( V_{GS} \) is less than zero, the situation is similar to that described above as \( V_{DS} \) is increased. The difference is that the depletion region is initially larger (at \( V_{DS} = 0 \)) and so the characteristic curve turns over and pinches off at lower current values.
Appendix D

The Spark Generator

The circuit used for the generation of sparks is as follows:

The low resistance primary winding P consists of a few turns of insulated copper wire wound over, but insulated from, an iron core. This primary coil is in series with a high-current power supply and the switch AK, which is opened and closed by rotating the cam B. The secondary winding S consists of a large number of turns wound around P, but insulated from it, and connected to the spark plug. (In cars the spark plugs are connected to the secondary via a distributor, which delivers a voltage to the right spark plug at the right time.) When AK is closed a steady current flows and a magnetic flux is induced in the primary. (The iron core amplifies the magnetic flux density.) When AK is opened this current is interrupted (i.e. the current is now changing) and a corresponding change in the magnetic flux through P is induced. This changing flux also threads the coils of S, and hence induces a voltage in the secondary circuit according to the transformer equation:

$$V_2 = \frac{n_2}{n_1}V_1,$$

where $V_2$ and $V_1$ are the induced voltages across the secondary and primary coils, respectively, and $n_2$ and $n_1$ are the number of turns in the secondary and primary coils. Due to the fact that $n_2 \gg n_1$, the secondary voltage is sufficiently high to cause a spark to appear across the gap in the circuit at the plug tip.

Finally, the capacitor C prevents a spark occurring between the points A and K as they are being separated, which would soon damage them. If C was not in the circuit, the voltage of the battery would appear immediately across AK when they are separated, thus causing a spark across the narrow gap. With C in the circuit, however, the capacitor begins to charge as soon as AK is opened, and so initially the voltage of the battery appears across the resistance of the winding and not AK. (You may understand this better if you have studied the capacitor (Experiment. 1) in the Electronics laboratory.)
Appendix E
Mechanism of the Breakdown of a Neon Diode

There are a number of processes going on inside the envelope of a neon diode before it is connected in a circuit.

1. There are always some electrons being released from the electrodes or the gas atoms by background radiation such as:
   (i) Ultra violet light, if it gets through the glass envelope, can eject photoelectrons from the metal cathode. If the metal surface is not atomically clean, visible light may suffice.
   (ii) γ-rays from the surroundings, e.g. bricks in the building, can release electrons from the electrodes or from gas molecules. These photo-electrons are energetic enough to pass through several millimetres of gas, knocking electrons from gas atoms.
   (iii) An occasional α-particle from radioactive contamination of the electrodes or the envelope will pass through the gas leaving a dense track of ionized atoms.
   (iv) A cosmic ray particle, usually a muon, may pass through the gas leaving a thin trail of ionized atoms. Cosmic ray ionization is likely to be only about 25% of that produced by other sources.

   Note: Some luminous watches are a considerable source of γ-rays. You may notice a change in the behaviour of the tube if you put your watch close to it. (Room lighting may also have to be excluded.)

2. If a voltage much lower than $V_S$ is applied across the electrodes, these ions will be collected constituting a current, but it is much too small to be measured without specially sensitive equipment. If the voltage is raised, electrons accelerating towards the anode may acquire enough energy in one mean free path to knock an electron out of the next gas atom they hit. To do this they require an energy of 21.47 electron volts, corresponding to the ionization potential of neon. In this way one electron can grow quickly to an avalanche, the number of electrons nearly doubling with each mean free path. The current, however, is still too small to be detected except by the use of an amplifier.

3. To produce a glow discharge and appreciable current, an avalanche must be able to breed more avalanches. This it can do by means of ultra violet light from excited atoms in the avalanche, or by electrons extracted from the cathode by electrostatic forces as positive ions approach just before they are collected. The probability of this is very low, and consequently the avalanches have to be large enough or numerous enough to ensure that at least one secondary electron is always extracted from the cathode to continue the discharge, thus making it self-maintaining. If the average number of secondary electrons resulting from an avalanche was only one, then frequently the number of secondaries would be zero, but occasionally it would be several. The first avalanche would then usually fail to breed. Alternatively, after waiting for several primary avalanches, one of them may give several secondaries leading to a few generations of avalanches which would then peter out. However, larger avalanches giving a larger average number of secondary electrons could ensure that, in spite of fluctuations, there will always be one or more secondaries to produce the next generation of avalanches. Since the avalanche size increases with the applied voltage, breakdown will occur when the voltage is made high enough. This is the breakdown voltage, $V_S$.

4. You can now see why the breakdown voltage is variable. There have to be enough positive ions or U.V. photons reaching the cathode to give a guaranteed continuing supply of secondary electrons. This can be achieved in two ways: either by waiting for a large enough group of electrons to be released by chance by the background radiation, giving many avalanches, or by raising the voltage to get big enough avalanches even if they arrive one at a time. Thus, if the voltage is building up quickly it may go higher before breakdown than it would do otherwise. Again, if the background is increased with U.V. light or a γ-source, breakdown will occur earlier, at a lower voltage.
5. Now, once avalanche breeding sets in, there is a copious supply of secondary electrons and the discharge can be maintained at a much lower voltage than the breakdown voltage. At a slightly lower voltage the supply of secondary electrons will be inadequate (smaller avalanches) and the discharge will go out. This is the *quenching voltage*, $V_q$.

6. The instant the discharge goes out there will be some positive ions still uncollected, and secondary electrons released during their collection will make it easier to start the discharge again if the voltage rises again immediately.
Appendix F  

X-Ray Production

Bremsstrahlung

In the photoelectric effect, a photon transfers all its electromagnetic energy to a bound electron; the photon's energy appears as the binding energy and kinetic energy of the photo-electron. The inverse effect is that in which an electron loses kinetic energy and, in so doing, creates one (or more) photons. This is an important process in the production of X-rays.

Consider the situation where a fast moving electron comes close to the positively charged nucleus of an atom and thus is deflected by it (Fig. 1). The electron experiences a large attractive force as a consequence of its interaction with the heavy, positively charged nucleus; hence it is diverted from its straight line path (i.e. accelerated). Quantum theory predicts that an accelerated electric charge (as in the case of the electron) will radiate electromagnetic energy in the form of discrete photons. It is therefore expected that a deflected electron will radiate one or more photons and thus it will leave the site of the collision with less kinetic energy than it had, such that:

\[(K_1 - K_2) = E_{\text{photon}}.\]

The radiation produced in such a collision is referred to as bremsstrahlung.

X-Ray Tubes

The X-rays you will use for your experiments are produced in an X-ray tube known as the hot-cathode type. This refers to the use of a heated tungsten filament as the electron source (the cathode). The anode is a heavy copper rod. An electric current through the tungsten filament heats the cathode to a high enough temperature so that the electrons have sufficient kinetic energy to overcome their binding to the cathode surface, and thus be released in thermionic emission.

When applying a large voltage between the cathode and the anode (in this case either 20 or 30 kV), the electrons from the tungsten filament are accelerated through a vacuum towards the copper target. On striking the target the electrons are decelerated and essentially brought to rest in...
collisions. Although most of this appears as thermal energy in the target, a small fraction goes into the production of electromagnetic radiation through the previous bremsstrahlung process. Figure 2 shows a typical spectrum arising from bremsstrahlung collisions of electrons with atoms. Note the continuous nature of the spectrum.

![Relative Intensity vs Frequency](image)

**Figure 2**

**Ionization**

Another process present in production of X-rays from the X-ray tube is excitation or ionization. When atoms are bombarded with high energy electrons, an inner electron from the atom may be excited or removed. When such an inner electron is displaced, a vacancy is created within the K shell which may be filled by the transition of an electron from a higher shell (e.g. the L or M shell).

The transition to the more bound state of the atom is accompanied by emission of a photon. The energy of this photon is dependent upon its initial state:

- a transition from the L shell to the K shell produces a $K_\alpha$ photon;
- a transition from the M shell to the K shell produces a $K_\beta$ photon.

The actual energies of the $K_\alpha$, $K_\beta$, ..., photons are determined by the spacing of the atomic energy levels and, hence, will be different for different atoms. In your case the target atom is copper and the characteristic X-rays are:

- $K_\alpha$: $\lambda = 0.154 \times 10^{-9}$ m
- $K_\beta$: $\lambda = 0.138 \times 10^{-9}$ m.

**Note:** $K_\gamma$ photons are of negligible intensity and therefore one would only expect to see X-rays of energies corresponding to $K_\alpha$ and $K_\beta$ contributing to the total spectrum of the X-ray tube.)
Appendix G  Mounting the Crystals

- Select the crystal to be mounted and place one of the short edges onto the step in the crystal post.
- Ensure that the major (long, broad) face having the "flat-matt" appearance, is sitting butted against the chamfered protrusion of the post (see Fig. 1, below).
- Screw the clamp until the crystal is held securely by the rubber jaw.

Note: The experimental face of the crystal is the face in contact with the chamfer on the post.)

Figure 1: Mounting of Cubic Crystals
Appendix H  

Reading a Vernier Scale

The Vernier Scale is used whenever one needs to make a measurement of distance or angle to an accuracy greater than that obtainable through direct visual reading of a linear scale.

The exact geometry of the Vernier Scale will often depend on the situation in which it is employed. Despite this, the principle of its working remains the same.

In using the Vernier, it is useful to realise that the measurement can be broken down into two parts. These are:

- **the visual**: this part of the measurement proceeds normally (where the ‘pointer’ of the measurement may be the ‘zero’ of the Vernier scale). The measurement is made to the limit of reading of the scale.
- **the Vernier**: this is the new part of the measurement: by reading the Vernier an extra significant figure can generally be obtained in the measurement.

**Construction of the Vernier**

The Vernier uses the linear reading scale of the measuring apparatus along with another scale which is scaled by a factor of 9:10 compared to the linear scale.

![Vernier Scale Diagram]

In the above situation, two markings from the Vernier line up with the linear scale. This is only because the reading is exactly 4mm. You can see that the ten markings on the Vernier span the space of only nine markings on the Linear scale. This means that generally only one of the Vernier markings will align with the linear scale. The figure that lines up most closely provides the next significant figure in your measurement.

Notice that if the pointer (the zero) was moved from 4 mm to 4.5 mm each of the markings on the Vernier scale would line up with a marking on the linear scale only once and that they would do this in turn from left to right. Thus the Vernier indicates faithfully the last significant figure of accuracy. Understanding this is understanding the functioning of the Vernier scale.

**Example:**

![Example Vernier Scale Diagram]
In order to read this scale we might employ the following method:

1. Read the linear part of the measurement, in this case, from the ‘zero’ of the Vernier. Doing this returns a result of **3.5 mm**.

2. Next, determine which marking on the Vernier scale most nearly lines up with the markings on the linear scale. Personally, I do this by scanning my eye across the scale and judging whether the Vernier scale is to the left or the right of the linear scale. When I cannot decide ‘left’ or ‘right’, I know that I have alignment. In the above measurement I would thus say: “right, right, right, don’t know, left, left...”, and thus determine that it is the **2** which most closely lines up with the linear scale. This means that I need to add **0.20 mm** to my earlier, linear reading.

3. As the Vernier scale has a limit of reading of **0.05 mm**, my uncertainty for this reading is **0.025 mm**, which would possibly, most fairly be rounded to **0.03 mm**. Thus my final result would be **3.70 ± 0.03 mm**.

**Exercises:**

Try reading the following scales for practice:

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**Solutions:**

1: 2.65 ± 0.03 mm.  
2: 4.75 ± 0.03 mm.  
3: 2.65 ± 0.03 mm.  
4: 2.23 ± 0.0005 mm.
# Appendix I

## S.I. Units

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Name of S.I. Unit</th>
<th>Symbol</th>
<th>S.I. Base Units</th>
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</thead>
<tbody>
<tr>
<td>frequency</td>
<td>hertz</td>
<td>Hz</td>
<td>1 Hz = 1/s</td>
</tr>
<tr>
<td>force</td>
<td>newton</td>
<td>N</td>
<td>1 N = 1 kg m / s²</td>
</tr>
<tr>
<td>energy</td>
<td>joule</td>
<td>J</td>
<td>1 J = 1 N m</td>
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<tr>
<td>power</td>
<td>watt</td>
<td>W</td>
<td>1 W = 1 J/s</td>
</tr>
<tr>
<td>quantity of electric charge</td>
<td>coulomb</td>
<td>C</td>
<td>1 C = 1 A s</td>
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<tr>
<td>electric potential,</td>
<td>voltmeter</td>
<td>V</td>
<td>1 V = 1 W/A</td>
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<td></td>
</tr>
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<td>electromotive force</td>
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<tr>
<td>electric capacitance</td>
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<td>F</td>
<td>1 F = 1 A s/V</td>
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<td>1 Ω = 1 V/A</td>
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<tr>
<td>inductance</td>
<td>henry</td>
<td>H</td>
<td>1 H = 1 V s/A</td>
</tr>
</tbody>
</table>

**Note:** The S.I. units have been expressed in terms of the S.I. base units, namely metre (m), kilogram (kg), second (s) and ampere (A). These are, of course, the units for the following respective quantities: length, mass, time and electric current.
Appendix J
Detector Construction and Operation

The basic feature of the operation of the detectors is the production of an electrical signal when radiation is detected. We therefore start with a simplified version of how the Geiger counter and the scintillation counter work.

The *Geiger counter* consists of a cylindrical case with an axial wire running through it; the cylinder being filled with a suitable mixture of gases (see Fig. 1). The axial wire is insulated from the cylindrical case and is held at a positive potential relative to the case by means of a D.C. power supply. When ionising radiation enters the counter, it ionises some of the gas molecules along its path, and the negative ions and/or electrons so formed are attracted to the anode whilst the positive ions are attracted to the cathode.

As the electrons are accelerated by the electric field between the electrodes towards the anode, they have collisions with other gas molecules, thereby causing further ionisation. This process of *charge multiplication* occurs many times. The net result is that a substantial negative charge is eventually dumped on the anode.

The *scintillation counter* consists of a transparent substance, known as a *scintillator* or *phosphor* (in your case a sodium iodide crystal impregnated with thallium), one face of which is optically coupled to a photomultiplier tube, the other faces being coated with a reflecting material. (A *photomultiplier* is an evacuated glass tube with an assortment of electrodes in it - see Fig. 2). When radiation interacts with the phosphor, it gives rise to tiny flashes of light which impinge on the end of the photomultiplier. The light entering the photomultiplier strikes the cathode, which is coated with a photosensitive material, causing it to emit photoelectrons. These are attracted to the next electrode, called a *dynode*, which is held positive relative to the cathode. The dynode is coated with a material which has the property that when one electron strikes it, more than one electron is liberated. These electrons are then attracted to the still more positive next electrode, where further electron multiplication occurs, and so on down the photomultiplier, until eventually a substantial burst of electrons is deposited on the anode.

Thus, with both types of detector, the net result of radiation interacting with it is the dumping of a burst of negative charge on the anode.
**Voltage Pulses**

The anode of a detector is connected to a high voltage power supply via a resistor, R, known as the load resistor, and is isolated from the preamplifier (the first piece of equipment connected to the detector) by a capacitor C. This capacitor allows the input terminal of the preamplifier to remain at a low voltage, i.e. the potential difference between the plates of C is normally close to V volts.

![Diagram](image)

In its normal state, the anode of the detector is at the same potential as the +ve terminal of the power supply. This is because, in the absence of any current between the anode and the cathode, no current flows through R. When the burst of negative charge is dumped on the anode, as a result of a radiation detection event, the potential of the anode is lowered. There is, therefore, a potential difference established across R, and a current flows through R, until the anode potential eventually rises to that of the +ve terminal of the power supply again. Physically, this current is simply the escape of the burst of electrons which was dumped on the anode. These electrons pass through the H.V. supply and on to earth.

The variation of the charge, and, therefore, of the voltage, on the anode will be a function of time as shown on the voltage- time graph. t is the time during which the negative charge is dumped on the anode - the time to produce the voltage drop.

The decay of the voltage drop is quite protracted because, as more of the electrons escape through R, the potential difference across R gets smaller, hence the current gets smaller, and the decay of the voltage drop gets slower. The complete potential variation, arising from the radiation detection event, is known as a voltage pulse.

Since the left-hand plate of C is connected to the anode with virtually zero resistance in between, this left-hand plate is essentially part of the anode, and the presence of negative charge on it during the time of the voltage pulse lowers the potential of the right-hand plate of C. Thus, the voltage pulse appears also on the right-hand plate of C, and hence, at the input of the preamplifier. The function of your electronics system is to count these voltage pulses.

**Scintillation Counter Electronics**

If your scintillation counter has two or more cable sockets in its end, the block diagram of your electronics is as follows:
However, if your scintillation counter has only one lead coming from it, your block diagram is as follows:

In this arrangement, the load resistance, $R$, of your scintillation counter is in the high voltage lead inside the preamplifier box.

The power lead between the amplifier and the preamplifier plugs into the back of the amplifier. This lead carries the power needed to operate the preamplifier circuits. Notice that the power leads between the power supply and the scintillation counter, including those which go via the preamplifier in the second block diagram, have longer and more heavily insulated plugs on them than have the signal cables. The corresponding sockets are also different. Never try to force one type of plug on to the other type of socket.

Identify all the components of your electronics, then read on and make yourself familiar with each "module".
(i) **Preamplifier**

The current through the load resistor, $R$, of the detector is small for most detectors, but for pulses to propagate along long cables (as is often required), without severe loss of amplitude, they must be generated by high current sources. It is, therefore, customary to feed detector pulses into a *preamplifier*, a circuit which can generate large current through the load resistor on its output terminal, in response to an input pulse. Such a circuit is not concerned with amplification of the pulse: in fact, it may even reduce the amplitude. The output pulse from the preamplifier is fed into the amplifier.

(ii) **Amplifier**

Most modern pulse electronics are designed to handle pulses with amplitudes up to 10 volts. An *amplifier*, as its name suggests, produces output pulses with larger amplitude than those presented at its input, and its “gain” controls are normally adjusted so that the pulses being studied are amplified to a size which conveniently covers this 10 V operating range. Your amplifier has two gain controls: a coarse control which allows substantial gain changes to be made in discrete steps, and a fine control which allows continuous control over a range comparable to one step of the coarse control.

Your amplifier is also designed to accept either positive or negative input pulses, the choice being made by a selector switch on the front panel. It gives output pulses regardless of the input pulse polarity. However, there is a choice available, by another selector switch, for unipolar or bipolar output pulses (see Fig. 5). The choice between these depends on the shape of the input pulses and the nature of the measurement being made.

(iii) **Single Channel Analyser**

In many applications, including all the experiments in this laboratory, one wants to count the pulses coming from the amplifier, or to count just those whose amplitudes fall in a particular voltage range. The *single channel analyser* (S.C.A.) has two control knobs. When the selector switch is set to “normal”, the *lower level* knob sets the minimum height (in volts) of pulses to which the S.C.A. will respond, and the *upper level* or window knob sets the maximum height. Thus an output pulse is generated only if the input pulse has an amplitude between the settings of these two knobs. All the output pulses are identical, and are about 5 V high. The operation of the S.C.A. with the selector switch set to "window" will be described later, when this mode of operation is needed.

(iv) **Counter**

All that remains to be done in the radiation detection procedure is to count the pulses from the S.C.A. This is done with the *counter* (more often known as the *scaler*), which displays
the running total as red numbers in a small window in the front panel. It has three controls which will be found useful: a selector switch to start and stop counting, a push-button to reset the display to zero, and a discriminator knob. The discriminator knob behaves in the same way as the lower level knob on the S.C.A., and is generally used only when pulses are fed directly from an amplifier into the counter. In our application, the counter will be counting only the 5 V pulses from the S.C.A.; any setting below 5 will, therefore, be satisfactory.

(v) Power Bin

Your high voltage power supply, amplifier, S.C.A. and counter all plug into a standard bin which has a power supply mounted along its back. This power supply provides all the power needed by these units for their operation.

(vi) Computer Interface

If you are using the computer to acquire your data, you first need to switch on the computer and run the data acquisition program. To do this double click the left mouse button on the Counter Icon in the Lab Tools Group. Make sure the counter is connected to the computer and is switched on at

- Once the data acquisition program starts a window called “Radiation Counter” will appear (see Figure 7)
In a typical experiment the following procedure is recommended

(i) Make sure the counter is connected to the computer and is switched on at the wall. The transformer should be set to 7.5 Volts.

(ii) Before testing the counter, your demonstrator should have setup the electronics so that the pulses coming from your detector peak at about 9 Volts. This process should be explained to you by your demonstrator in the first prac class. In later prac classes you may wish to setup the electronics yourself.

(iii) Before testing your computer counter make sure that the “Data Storage” button is off. If this is left on all your test readings will be written to a file.

(iv) Set some test parameters, (for example 5 samples with count time of 1 second) and click on the “start” button. Your measurements should appear in the graph window joined by a line, if data doesn’t appear in the graph window call your demonstrator.

(v) Once the number of samples and count time have been determined for your experiment these values need to be set in the appropriate boxes. (Note: Quite often you may need to take a background radiation measurement before beginning the experiment. In this case your sample number should be set to 1.) Remember to set the “Data Storage” button to the “on” position before collecting data. It is usually a good idea to change the name of the file in which the data is to be stored. The convention is to use the .txt extension for data files of this type.

(vi) When you have finished collecting data you can analyse and plot the data using another software package like “Microsoft Excel”.