I. (a) (i) Correct diagram showing the set-up (air track and vehicles + cork and pin device).
An air track enables Perspex vehicles to move with negligible friction and multiflash photography (or photogates and datalogger connected to a computer) to measure velocities.
A completely inelastic collision is made between a vehicle of mass \( m_1 \) moving in from the left and one of mass \( m_2 \) initially at rest using pin and cork.
The initial velocity of \( m_1 \) before collision and the final velocity of them after collision can be obtained from the multiflash photograph.
We can check whether the initial and final total momentum are equal, i.e.
\[
m_1 \bar{u}_1 = (m_1 + m_2) \bar{v} \quad (\bar{u}_2 = 0 \text{ initially})
\]
(ii)

\[
\begin{align*}
\text{Before collision} & \quad \text{After collision} \\
\begin{array}{c}
\bullet \quad \bullet \quad \bullet \\
\text{m}_1 \quad \text{u}_1 \quad \text{u}_2 \\
\text{m}_2
\end{array}
\begin{array}{c}
\bullet \quad \bullet \quad \bullet \\
\text{m}_1 \quad \text{v}_1 \quad \text{v}_2 \\
\text{m}_2
\end{array}
\end{align*}
\]

Suppose two spheres of masses \( m_1 \) and \( m_2 \) collide and bounce off on a smooth horizontal ground as shown.
By Newton's third law, the action and reaction during collision are equal and opposite (or \(-F_1 = F_2\)).
(Take the direction towards the right to be positive,)

\[
-\frac{m_1(v_1 - u_1)}{\Delta t} = \frac{m_2(v_2 - u_2)}{\Delta t} \quad (\text{By Newton's second law})
\]

where \( \Delta t = \text{collision time} \)
\( F_1 = \text{rate of change of momentum of } m_1 \)
\( F_2 = \text{rate of change of momentum of } m_2 \)

(b) Process 1: The law of conservation of momentum can be applied to the system since there are no net external forces acting on the system along the horizontal direction.
The tension in the rod and the weight of the system are vertical, and the frictional forces between the bullet and the sphere are internal forces.
(Or The collision time is short enough to neglect the effect of external forces.)
The law of conversation of mechanical energy cannot be applied to the system since work is done against friction and some of the bullet's kinetic energy is changed to heat.

Process 2: The law of conservation of momentum cannot be applied to the system once the sphere moves since the tension is now an external force.
The law of conservation of mechanical energy can be applied to the system since no work is done by the tension on the system because the direction of motion of the sphere is always perpendicular to the tension.
The kinetic energy of the system is converted to its potential energy.
1. (c) Since total momentum is conserved,
\[ m_1 \vec{u}_1 = m_1 \vec{v}_1 + m_2 \vec{v}_2 \]

As the collision is elastic, total kinetic energy is conserved
\[ \frac{1}{2} m_1 u_1^2 = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 \]

For a right-angled triangle, from (i)
\[ (m_1 u_1)^2 = (m_1 v_1)^2 + (m_2 v_2)^2 \]

\[ \frac{1}{2} m_1 u_1^2 = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 \left( \frac{m_2}{m_1} \right) \]

Compare (i) and (ii), we have \( \frac{m_2}{m_1} = 1 \), i.e. \( m_1 = m_2 \)

2. (a) - the oscillation of the particles in the medium and the direction of propagation
- polarisation
(Accept other reasonable answers)
Example: Electromagnetic waves are transverse waves
Sound waves are longitudinal waves

(b) A sound wave is produced by a vibrating object and the disturbance is transferred to nearby air particles, causing them to oscillate to-and-fro along the direction of travel of the wave (or vibrates longitudinally).
The disturbance is passed on to air particles nearby which results in a sound wave carrying energy from the source to the ear where the succession of compressions and rarefactions travel in air causing the ear-drum to vibrate.
The sensation of ‘sound’ is then interpreted by the brain through electrical signals generated by the nerves.
The displacement of an air particle varies along the path of a travelling sound wave as follows:

Correct graph (sine curve + x-axis labelled) 1
Correct labelling of R and C. 1
(i) By measuring the separation $d$ between the 1st and the nth ‘in-phase’ positions, the wavelength can be found by 
$$\lambda = \frac{d}{n-1}.$$

The frequency $f$ can be found from the time base together with the number of divisions for a complete wave displaced by the CRO and the speed is given by $v = \phi n$. The frequency of the signal generator is chosen such that the microphone is the most sensitive to that frequency, say, 500 Hz.

The separation between the loudspeaker and the microphone should be 1~2 m apart so that a few ‘in-phase’ positions can be found.

(ii) To keep the direct and reflected waves always in phase. (Accept other reasonable answers)
3. (a) (i) 

Axes labelled and showing path ABCDE

Indicate \( \frac{\varepsilon R}{r+R} \) and \( \frac{2(\frac{\varepsilon R}{r+R})}{3} \)

Constant reading for AB, DE and drop for the wires

\[ \begin{align*}
&\text{voltmeter reading} \\
&\frac{\varepsilon R}{r+R} \\
&\frac{2(\frac{\varepsilon R}{r+R})}{3} \\
&0 \\
&A \quad B \quad C \quad D \quad E
\end{align*} \]

path length along circuit

Since \( R \propto \frac{1}{A} \), \( R_{BC} : R_{CD} = 1:2 \),

\[ V_{BC} : V_{CD} = 1:2 \] as the same current \( \frac{\varepsilon}{r+R} \) flows through the wires.

\( AB, DE \) : Since the resistances of the connecting wires are negligible, there is no energy dissipated as the charge \( q \) travels along the connecting wires.

\( BC, CD \) : When the charge \( q \) passes through wires \( BC \) and \( CD \), the amount of electrical potential energy \( qV \) (\( qV_{BC} \) and \( qV_{CD} \)) are changed to heat.

\( EA \) : When the charge \( q \) passes through the cell, the amount of energy \( q \left( \frac{\varepsilon R}{r+R} \right) \) (or \( qV_{AB} \)) is transferred (or work done) from the chemical energy of the cell.

(ii) The p.d. applied across the conductor would set up an electric field that causes the free electrons to accelerate (or gain velocity / gain kinetic energy) in a direction opposite to the electric field / conventional current \( I \).

On colliding with the lattice ions in the conductor, the electrons on average lose the energy gained to the lattice ions (or lattice ions gain vibrational energy) and then accelerate again.

Due to the bombardment of the fast-moving electrons, the lattice ions gain vibrational energy resulting in a temperature rise and thus heat is generated (both kinetic and potential energy as they vibrate more vigorously and with greater amplitude).

(b) (i) All the free (or conduction) electrons drift with an average speed \( v \) along the conductor in the direction opposite to the conventional current \( I \).

The total number of free electrons in the conductor is \( nLA \)

The force acting on all the free electrons in the conductor is

\[ F = (nLA) Bev \]
\[ = (nAev)LB \] (\( \because I = nAev \))
\[ = ILB \]
In a moving conductor, free electrons are carried along and therefore experience a magnetic force at right angles to the field and to the direction of motion of the conductor.

According to the Fleming’s left-hand rule, free electrons are forced to end \( X \). As a result of charge separation (or electrons accumulation), an electric field is created inside the conductor pointing towards end \( X \).

No further electrons accumulate to \( X \) when

\[
\text{Electric force acting on electron} = \text{Magnetic force acting on the same electron}
\]

A p.d. \( \varepsilon \) is developed between the ends \( X \) and \( Y \) of the conductor of length \( L \).

\[
\varepsilon = \frac{E}{L} = BLu
\]

The number of molecules is very large and they move randomly. This fact makes the vector sum of the total momentum change of the bombarding molecules constant during the finite time in which observation is made.

If the collisions were inelastic, the average speed of the gas molecules would decrease with time due to the lost of kinetic energy during collisions. This would cause a decrease in the temperature and the pressure even though nothing had been done on the gas. Because this phenomenon is never observed, the collisions cannot be inelastic.

When temperature increases the average speed of gas molecules increases, the average momentum transferred to the container wall per collision then increases. The volume has to increase until the frequency of collision of gas molecules decreases such that the total momentum transferred per unit time per unit area remains unchanged in order to keep the pressure constant. (give \( \frac{1}{2} M \) for total momentum unchanged)

Record several pairs of readings of volume and temperature between 0 °C to 100 °C and plot volume against temperature. (Accept using the length of air column to be the volume at 0°C and 100°C.) Produce the graph to cut the temperature axis. The intercept on the temperature axis is the approximate value of the absolute zero.

At low temperature and high pressure, the density of the gas would increase such that the range of intermolecular force is no longer much smaller than the average separation between molecules, which is an assumption of the kinetic theory. (Or the total size of the molecules is not negligible compared with the volume of the container.)
5. (a) The binding energy of a nucleus is the energy needed to split the nucleus into its individual nucleons. (Or other definition such as that in terms of mass defect.)

Correct shape of binding energy curve

(i) The fusion of hydrogen can produce more energy, because the binding energy per nucleon curve around the position of hydrogen is much steeper than that of uranium.

(ii) Iron $^{56}$Fe is at/near the top of the binding energy curve. That means both fission and fusion of iron would absorb energy rather than release energy.

(b) (i) The ground state is the most stable state in which the electron is in its lowest energy available, i.e. $E_i$ which is $-13.6$ eV.

The excitation energy is the right amount of energy absorbed to raise the electron from the ground state to the excited energy, i.e. $E_m - E_i$ where $1 < m < \infty$.

The ionization energy is the energy just sufficient to remove the electron from the atom, i.e. for a hydrogen atom at ground state $E_\infty - E_i = 13.6$ eV.

(ii) When an excited atom loses energy, the energy level of the electron changes from $E_m$ to $E_n$ where $E_m > E_n$.

The frequency $f$ of the electromagnetic radiation emitted is given by: $E_m - E_n = hf$, and this frequency corresponds to a particular bright line in the observed spectrum.

(c) (i) The absorption spectrum (dark lines against the sun's continuous spectrum) is characterized by the composition of the outer atmosphere of the sun. When white light of the sun's continuous spectrum passes through, the atoms in the atmosphere of the sun absorb the right amount of energy $hf$ corresponding to their own characteristic wavelengths and then emit electromagnetic radiation of the same frequency $f$ spontaneously but in all directions.

The line in the spectrum corresponding to this frequency appears dark comparing with the background continuous spectrum.

By comparing the wavelengths of these dark lines in the sun's spectrum with the characteristic spectrum of known elements, the composition of the sun's atmosphere can be identified.

(ii) The positions of the spectral lines of an identifiable element in the star are compared with their positions in the spectrum produced in the laboratory. The shift of positions is due to the Doppler effect and hence the star's velocity along the line of sight can be estimated.