1. (a) The gun should aim at a point above $O$ to compensate for the drop in vertical distance of the ball bearing due to gravity. When aiming at $B$, time for the bearing to reach $O$ equals time for an object to fall freely from $B$ to $O$. Since the horizontal component of the velocity is less, the time of flight is longer and the vertical distance $O_B$ is greater than distance $D$.

(b) (i) The figure should include a breakable switch (thin aluminum foil or light beam and photo-gate) just in front of the gun, an electromagnet and a correct closed circuit. Brief description of the set-up.

When the compressed spring is released, the bearing breaks the switch and the circuit is broken. At the same time, the block falls down as no current flows in the electromagnet and it will be hit by the bearing at a position underneath.

(ii) Since the horizontal and vertical motions are independent, the bullet can still hit the block though at a higher position due to the shorter time of flight (larger horizontal speed of bullet).

(iii) (I) For the same amount of energy given to a heavier bearing, the horizontal velocity of the ball bearing is smaller. The time of flight is longer and the block will be hit at a position lower than $D$ underneath.

(II) Because part of the initial elastic energy is dissipated by the gun, the horizontal velocity of the ball bearing is smaller. The time of flight is longer and the block will be hit at a position lower than $D$ underneath.

(c) Let $v$ be the speed of the cannon ball,

$$mg = m\frac{v^2}{r}$$

$$v = \sqrt{(10 \text{ m s}^{-2})(6400 \times 10^3 \text{ m})}$$

$$= 8000 \text{ m s}^{-1} \text{ or } 8 \text{ km s}^{-1}$$

The gravitational pull changes the direction of the velocity of the cannon ball and so it follows a circular path of radius equals that of the earth. The speed of the cannon ball thus remains constant and its acceleration, which is constant in magnitude, is centripetal.
2. (a) (i) When waves/pulses cross the total/resultant displacement is the (vector) sum of the individual displacements due to each pulse at that point.

(ii) The reflected wave is of the same frequency, wavelength and similar amplitude travels along the string in the opposite direction.

Or The resultant waveform does not seem to be travelling along the string, stationary waves formed with antinode at the free end.

(b) Connect two loudspeakers in parallel to the low impedance output of a signal generator, set at, say, 4 kHz. The fringes (or alternate maximum and minimum loudness) are detected by moving a microphone feeding a CRO via a pre-amplifier along XY.

At points where the path difference from the two speakers equals $n\lambda$, where $\lambda$ is the wavelength of the sound waves generated, the waves arriving at that point are in phase and reinforcement/constructive interference occurs and vice versa.

The effect of unwanted reflections (e.g. from objects nearby) is minimized by working between two benches, or still better, out of doors.
2. (c) (i) For a certain depth of water, the waves from a point source travel at a constant speed in all directions. Therefore, the time taken for the tsunami wavefront to reach a certain place depends on the distance of that place from the epicentre. The tsunami waves thus took about 2 hours to travel 1500 km to Sri Lanka and in proportion about 3 hours 20 minutes to travel 2500 km to Maldives (i.e. $v = \frac{s}{t}$, ½ mark for theory, ½ mark for calculation).

(ii) As the wavelength of the tsunami waves is very long (over 100 km), diffraction of waves is significant and the waves can diffract at the tip of Sumatra and spread to Phuket situated in the geometrical shadow.

(iii) Since energy $\propto \lambda^2$, when tsunami waves reach the shore which is shallower, the wave speed decreases. As the energy remains unchanged, therefore the wave amplitude increases accordingly.

3. (a) (i) An electric field is a region in which a static charged body experiences an electric force.

Dip a pair of electrodes in a dish of (castor) oil. Connect the electrodes to an E.H.T. power supply (of 4 kV). Sprinkle particles (such as semolina, grass seeds) evenly over the oil surface. The particles will align with the electric field set up between the electrodes.

The following field patterns would be observed when switching on the E.H.T.:

(i) Direction of a field line is the direction of electric force acting on a test charge, which must be unique as the test charge should move only in one direction.

(b) (i) The copper disc starts spinning when the bar magnet is rotated. Since the magnetic flux change in the disc induces eddy currents in it and these try to reduce the effect (relative motion between the two) causing them according to Lenz’s law. Therefore the disc starts moving in the same direction as the magnet and tries to catch it up so as to eliminate their relative motion.

If the bar magnet and the copper disc are interchanged, the magnet will follow the rotation of the disc as well.
3. (b) (ii) The rate of change of magnetic flux in the fixed copper disc would increase and thus more eddy currents induced in it / greater heating results / greater opposition to the motion / rotation of the bar magnet.  

(c) (i) In a d.c. motor, a permanent magnet provides a (radial) magnetic field. When a current passes through the loop, the magnetic forces on the two arms forms a couple and rotates the coil in a clockwise direction. The coil reaches the vertical position and overshoots slightly. Then the commutators cause the current through the loop to reverse. The directions of the forces in the two arms are reversed such that the couple and the sense of rotation remains unchanged (clockwise).

(ii) When starting a motor, the armature is at rest initially and the back e.m.f. \( \varepsilon_b \) is zero. Since \( V - \varepsilon_b = Ir \), the armature current \( I \) then equals \( V/r \) would be very large as armature resistance \( r \) is very small. The ‘starting’ resistance is introduced to avoid burning out the armature coil. As the motor gains speed, the back e.m.f. in the armature coil increases, the ‘starting’ resistance can then be reduced.

4. (a) (i) Neutrons ejected from nuclei in the atmosphere by cosmic rays turn nitrogen into carbon-14.

\[
^{14}\text{N} + ^{1}\text{n} \rightarrow ^{14}\text{C} + ^{1}\text{H}
\]

Subsequently \(^{14}\text{C}\) forms radioactive carbon dioxide and may be taken by plants and trees for making carbohydrates by photosynthesis.

(ii) When an organism dies it ceases to take up fresh carbon and so over time the proportion of \(^{14}\text{C}\) in the dead organism decreases as a result of decay. By measuring the residual activity, the elapsed time since death of any ancient carbon-containing material such as wood can be estimated. A time-independent level of \(^{14}\text{C}\) activity for the past is assumed or the \(^{14}\text{C}\) reservoir has remained constant through time.

(b) (i) No, because coal formed from the compressed remains of plants practically contains no remaining \(^{14}\text{C}\) so they cannot be dated because the half-life of \(^{14}\text{C}\) is only 5568 years, therefore the acceptable carbon-14 dating range: 0 – 60000 years, about 10 half-lives.

(ii) Because fossil fuels are predominantly material of infinite geological age (e.g. coal, petroleum), whose \(^{14}\text{C}\) content is nil, the carbon dioxide so produced would lower the \(^{14}\text{C}\) concentration, in the form of CO\(_2\), in the atmosphere. Therefore through the interchange of CO\(_2\) between the atmosphere and living organisms the concentration of \(^{14}\text{C}\) in them would be lowered.
4. (c) (i) The binding energy per nucleon of the fission products is greater than that of the heavy parent nucleus, e.g. uranium. Energy will be released.  
(ii) Fuel: highly enriched uranium (over 80% U-235) for an atomic bomb while enriched uranium (about 3% U-235) for a nuclear reactor 
Neutrons: Slow neutrons are required for a nuclear reactor / 
On average only 1 neutron from each fission produces another fission

5. (a) (i) 

Transistor characteristics:

(1) $I_B = 0$ if $V_{BE} = V_{in} < -0.7 \text{ V}$.
Therefore $I_C = 0$ and $V_{CE} = 9 - I_C R_L = 9 \text{ V}$

(2) When $V_{BE}$ exceeds $-0.7 \text{ V}$, a collector current flows. As $V_{in}$ increases, both $I_B$ and $I_C$ increase. $V_{CE} = 9 - I_C R_L$ will decrease linearly with $V_{in}$ as long as $I_C R_L < 9 \text{ V}$

(3) When $I_C$ is increased to $I_C R_L \approx 9 \text{ V}$, saturation occurs. $V_{CE} \approx 0 \text{ V}$ for any further increase of $V_{in}$.

(ii) As a switch, the base bias has to make the collector current either zero or maximum, i.e. $R_B$ decreases such that the linear part (2) of the graph is nearly vertical.
When $I_C = 0$, $V_{CE} = V_{CC} = 9 \text{ V}$ the transistor is cut off and when $I_C = \text{ maximum}$, $V_{CE} \approx 0 \text{ V}$ the transistor is saturated.
Switching occurs electrically and may be done by taking the input from another circuit. Switching can occur millions of times a second.
Two capacitors $C_1, C_2$ should be added as below:

\[
\begin{align*}
V_\text{CE} &= 4.5 \text{ V} \\
I_a &= \frac{(V_{\text{in}} - 0.7)}{R_a} \\
I_c &= \beta I_B = \frac{(V_{\text{in}} - 0.7)}{R_B} \\
V_{\text{CE}} &= 9 - I_c R_L = 9 - \beta (V_{\text{in}} - 0.7) \frac{R_L}{R_B} \\
\text{Voltage gain} &= \frac{v_o}{v_i} = \frac{\Delta V_{\text{CE}}}{\Delta V_{\text{in}}} = -\beta \frac{R_L}{R_B}.
\end{align*}
\]

$C_1, C_2$ block the d.c. components of the input signal and the output respectively.

Without connecting to the varying signal $v_o$, $V_{\text{in}}$ is adjusted until $V_{\text{CE}} = 4.5 \text{ V}$ so that there is room for swing of the output above and below the quiescent state.

\[
\begin{align*}
I_B &= \frac{(V_{\text{in}} - 0.7)}{R_B} \\
I_c &= \beta I_B = \frac{(V_{\text{in}} - 0.7)}{R_B} \\
V_{\text{CE}} &= 9 - I_c R_L = 9 - \beta (V_{\text{in}} - 0.7) \frac{R_L}{R_B} \\
\text{Voltage gain} &= \frac{v_o}{v_i} = \frac{\Delta V_{\text{CE}}}{\Delta V_{\text{in}}} = -\beta \frac{R_L}{R_B}.
\end{align*}
\]

(ii) $R_L = 0$ (short-circuit), identified by resistance checking.

$R_B = \infty$ (open-circuit), identified by resistance checking.

(Accept other reasonable answers)