1a. Monochromatic light from two identical lamps arrives on a screen. The intensity of light on the screen from each lamp separately is $I_0$. On the axes, sketch a graph to show the variation with distance $x$ on the screen of the intensity $I$ of light on the screen.
1b. Monochromatic light from a single source is incident on two thin, parallel slits. [3 marks]

The following data are available.

- Slit separation = 0.12 mm
- Wavelength = 680 nm
- Distance to screen = 3.5 m

The intensity \( I \) of light at the screen from each slit separately is \( I_0 \). Sketch, on the axes, a graph to show the variation with distance \( x \) on the screen of the intensity of light on the screen for this arrangement.

1c. The slit separation is increased. Outline one change observed on the screen. [1 mark]
There is a proposal to power a space satellite X as it orbits the Earth. In this model, X is connected by an electronically-conducting cable to another smaller satellite Y.

2a. Satellite X orbits 6600 km from the centre of the Earth. Mass of the Earth = $6.0 \times 10^{24}$ kg

Show that the orbital speed of satellite X is about 8 km s$^{-1}$.

Satellite Y orbits closer to the centre of Earth than satellite X. Outline why

2b. the orbital times for X and Y are different.

2c. satellite Y requires a propulsion system.
2d. The cable between the satellites cuts the magnetic field lines of the Earth at right angles.

Explain why satellite X becomes positively charged.

2e. Satellite X must release ions into the space between the satellites. Explain why the current in the cable will become zero unless there is a method for transferring charge from X to Y.
2f. The magnetic field strength of the Earth is 31 µT at the orbital radius of the satellites. The cable is 15 km in length. Calculate the emf induced in the cable.

\[ E = -\frac{\Delta \Phi}{\Delta t} \]

\[ E = -\frac{B \cdot A \cdot \omega}{\Delta t} \]

\[ E = -\frac{31 \times 10^{-6} \cdot 15 \cdot 10^3 \cdot 2\pi \cdot 15}{\Delta t} \]

2g. The cable acts as a spring. Satellite Y has a mass \( m \) of 3.5 \( \times \) 10^2 kg. Under certain circumstances, satellite Y will perform simple harmonic motion (SHM) with a period \( T \) of 5.2 s.

Estimate the value of \( k \) in the following expression.

\[ T = 2\pi \sqrt{\frac{m}{k}} \]

Give an appropriate unit for your answer. Ignore the mass of the cable and any oscillation of satellite X.

2h. Describe the energy changes in the satellite Y-cable system during one cycle of the oscillation.

\[ \text{Energy change} = \text{KINETIC energy change} + \text{POTENTIAL energy change} \]

\[ \text{KINETIC energy change} = \int F \cdot v \, dt \]

\[ \text{POTENTIAL energy change} = \int -mg \cdot \Delta y \, dt \]

Integration of forces and work done.
Yellow light from a sodium lamp of wavelength 590 nm is incident at normal incidence on a double slit. The resulting interference pattern is observed on a screen. The intensity of the pattern on the screen is shown.

3a. Explain why zero intensity is observed at position A. [2 marks]

3b. The distance from the centre of the pattern to A is $4.1 \times 10^{-2}$ m. The distance from the screen to the slits is 7.0 m.

Calculate the width of each slit.

Calculate the separation of the two slits.
3c. Calculate the separation of the two slits. [2 marks]

The double slit is replaced by a diffraction grating that has 600 lines per millimetre. The resulting pattern on the screen is shown.

3d. State and explain the differences between the pattern on the screen due to the grating and the pattern due to the double slit. [3 marks]
3e. The yellow light is made from two very similar wavelengths that produce two lines in the spectrum of sodium. The wavelengths are 588.995 nm and 589.592 nm. These two lines can just be resolved in the second-order spectrum of this diffraction grating. Determine the beam width of the light incident on the diffraction grating.

4a. A student is investigating a method to measure the mass of a wooden block by timing the period of its oscillations on a spring.

4a. Describe the conditions required for an object to perform simple harmonic motion (SHM).
A 0.52 kg mass performs simple harmonic motion with a period of 0.86 s when attached to the spring. A wooden block attached to the same spring oscillates with a period of 0.74 s.

4b. Calculate the mass of the wooden block. [2 marks]

4c. In carrying out the experiment the student displaced the block horizontally by 4.8 cm from the equilibrium position. Determine the total energy in the oscillation of the wooden block. [3 marks]

4d. A second identical spring is placed in parallel and the experiment in (b) is repeated. Suggest how this change affects the fractional uncertainty in the mass of the block. [3 marks]
With the block stationary a longitudinal wave is made to travel through the original spring from left to right. The diagram shows the variation with distance $x$ of the displacement $y$ of the coils of the spring at an instant of time.

A point on the graph has been labelled that represents a point $P$ on the spring.

4e. State the direction of motion of $P$ on the spring. [1 mark]

4f. Explain whether $P$ is at the centre of a compression or the centre of a rarefaction. [2 marks]

5a. Outline the conditions necessary for simple harmonic motion (SHM) to occur. [2 marks]
A buoy, floating in a vertical tube, generates energy from the movement of water waves on the surface of the sea. When the buoy moves up, a cable turns a generator on the sea bed producing power. When the buoy moves down, the cable is wound in by a mechanism in the generator and no power is produced.

The motion of the buoy can be assumed to be simple harmonic.

5b. A wave of amplitude 4.3 m and wavelength 35 m, moves with a speed of 3.4 m s$^{-1}$. Calculate the maximum vertical speed of the buoy.

5c. Sketch a graph to show the variation with time of the generator output power. Label the time axis with a suitable scale.
Water can be used in other ways to generate energy.

5d. Outline, with reference to energy changes, the operation of a pumped storage hydroelectric system. 

5e. The water in a particular pumped storage hydroelectric system falls a vertical distance of 270 m to the turbines. Calculate the speed at which water arrives at the turbines. Assume that there is no energy loss in the system.

5f. The hydroelectric system has four 250 MW generators. Determine the maximum time for which the hydroelectric system can maintain full output when a mass of $1.5 \times 10^{10}$ kg of water passes through the turbines.
5g. Not all the stored energy can be retrieved because of energy losses in the system. Explain **two** such losses.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
</tr>
</tbody>
</table>
A student investigates how light can be used to measure the speed of a toy train.

Light from a laser is incident on a double slit. The light from the slits is detected by a light sensor attached to the train.

The graph shows the variation with time of the output voltage from the light sensor as the train moves parallel to the slits. The output voltage is proportional to the intensity of light incident on the sensor.

6a. Explain, with reference to the light passing through the slits, why a series of voltage peaks occurs. [3 marks]
6b. The slits are separated by 1.5 mm and the laser light has a wavelength of $6.3 \times 10^{-7}$ m. [1 mark]

The slits are 5.0 m from the train track. Calculate the separation between two adjacent positions of the train when the output voltage is at a maximum.

---

6c. Estimate the speed of the train. [2 marks]

A student investigates how light can be used to measure the speed of a toy train.

Light from a laser is incident on a double slit. The light from the slits is detected by a light sensor attached to the train.

The graph shows the variation with time of the output voltage from the light sensor as the train moves parallel to the slits. The output voltage is proportional to the intensity of light incident on the sensor.
As the train continues to move, the first diffraction minimum is observed when the light sensor is at a distance of 0.13 m from the centre of the fringe pattern.

6d. Determine the width of one of the slits. [2 marks]
6e. Suggest the variation in the output voltage from the light sensor that will be observed as the train moves beyond the first diffraction minimum.
6f. In another experiment the student replaces the light sensor with a sound sensor. The train travels away from a loudspeaker that is emitting sound waves of constant amplitude and frequency towards a reflecting barrier.

The graph shows the variation with time of the output voltage from the sounds sensor.

Explain how this effect arises.
7a. Police use radar to detect speeding cars. A police officer stands at the side of the road and points a radar device at an approaching car. The device emits microwaves which reflect off the car and return to the device. A change in frequency between the emitted and received microwaves is measured at the radar device.

The frequency change $\Delta f$ is given by

$$\Delta f = \frac{2fv}{c}$$

where $f$ is the transmitter frequency, $v$ is the speed of the car and $c$ is the wave speed.

The following data are available.

Transmitter frequency $f = 40 \text{ GHz}$ $\Delta f = 9.5 \text{ kHz}$ Maximum speed allowed = $28 \text{ m s}^{-1}$

(i) Explain the reason for the frequency change.
(ii) Suggest why there is a factor of 2 in the frequency-change equation.
(iii) Determine whether the speed of the car is below the maximum speed allowed.
7b. Airports use radar to track the position of aircraft. The waves are reflected from the aircraft and detected by a large circular receiver. The receiver must be able to resolve the radar images of two aircraft flying close to each other.

The following data are available.

- Diameter of circular radar receiver = 9.3 m
- Wavelength of radar = 2.5 cm
- Distance of two aircraft from the airport = 31 km

Calculate the minimum distance between the two aircraft when their images can just be resolved.
Monochromatic light is incident normally on four thin, parallel, rectangular slits.

The graph shows the variation with diffraction angle $\theta$ of the intensity of light $I$ at a distant screen.

$I_0$ is the intensity of the light at the middle of the screen from one slit.

8a. Explain why the intensity of light at $\theta=0$ is $16/I_0$. [3 marks]
8b. The width of each slit is 1.0µm. Use the graph to
(i) estimate the wavelength of light.
(ii) determine the separation of two consecutive slits.

8c. The arrangement is modified so that the number of slits becomes very large. Their separation and width stay the same.

(i) State two changes to the graph on page 20 as a result of these modifications.
(ii) A diffraction grating is used to resolve two lines in the spectrum of sodium in the second order. The two lines have wavelengths 588.995nm and 589.592nm. Determine the minimum number of slits in the grating that will enable the two lines to be resolved.
A longitudinal wave is travelling in a medium from left to right. The graph shows the variation with distance $x$ of the displacement $y$ of the particles in the medium. The solid line and the dotted line show the displacement at $t=0$ and $t=0.882$ ms, respectively.

The period of the wave is greater than 0.882 ms. A displacement to the right of the equilibrium position is positive.

9a. (i) Calculate the speed of this wave.  
(ii) Show that the angular frequency of oscillations of a particle in the medium is $\omega=1.3\times10^3 \text{rads}^{-1}$.
9b. One particle in the medium has its equilibrium position at \( x = 1.00 \) m. [4 marks]

(i) State and explain the direction of motion for this particle at \( t = 0 \).

(ii) Show that the speed of this particle at \( t = 0.882 \) ms is \( 4.9 \text{ms}^{-1} \).
9c. The travelling wave in (b) is directed at the open end of a tube of length 1.20 m. The other end of the tube is closed.

(i) Describe how a standing wave is formed.

(ii) Demonstrate, using a calculation, that a standing wave will be established in this tube.