INSTRUCTIONS:

1. Write your **Student Personal Identification Number (SPIN)** on the top right hand corner of this booklet.

2. Answer **ALL QUESTIONS**. Write your answers in the spaces provided in this booklet. If you need more spaces for answers, ask the Supervisor for extra paper. Write your SPIN on all extra sheets used and clearly number the questions. Attach the extra sheets at the appropriate places in this booklet.

3. In addition to this, four marks will be awarded for correct use of significant figures and a further four marks will be awarded for correct use of units of measurement.

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Check that this booklet contains pages 2-27 in the correct order and that none of these pages is blank.

Some useful formulae are given on Sheet 209/2.

YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.
Question 1: HOLLOW TUBE AND TUNING FORK

A hollow tube of length $L$ open at both ends as shown in Figure 1.1 below is held in midair. A tuning fork with a frequency $f_0$ vibrates at one end of the tube and causes the air in the tube to vibrate at its fundamental frequency. Express your answers in terms of $L$ and $f_0$.

**Figure 1.1**

a. Calculate the wavelength of the sound.

Wavelength = ______________

b. Calculate the speed of sound in the air inside the tube.

Speed = ______________
c. The tube is submerged in a large, graduated cylinder filled with water as shown in Figure 1.2. The tube is slowly raised out of the water and the same tuning fork, vibrating with frequency $f_0$, is held a fixed distance from the top of the tube.

**Figure 1.2**

Determine the height $h$ of the tube above the water when the air column resonates for the first time. Express your answer in terms of $L$. 

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| Skill level 3 | 3 | 2 | 1 | 0 | NR |
Question 2: THE VIOLIN SOUND

When a note is played on a violin, the sound it produces consists of the fundamental and many overtones.

Figure 1.3 shows the shape of the string for a stationary wave that corresponds to one of these overtones. The positions of maximum and zero displacement for one overtone are shown. Points A and B are fixed. Points X, Y, and Z are points on the string.

Figure 1.3

![Stationary wave diagram]

a. The frequency of this overtone is 780 Hz.
   i. Show that the speed of a progressive wave on this string is about 125 m.s^{-1}.

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   ii. Calculate the time taken for the string at point Z to move from maximum displacement.

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Time = _______________________________
b. The violinist presses on the string at C to shorten the part of the string that vibrates. Figure 1.4 shows the string between C and B vibrating in this fundamental mode. The length of the whole string is 320 mm and the distance between C and B is 240 mm.

**Figure 1.4**

![Diagram of a string between points A and B with C marked as a point of contact.](image)

Calculate the wavelength of this stationary wave.

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Wavelength = __________________________

**Question 3: DIFFRACTION GRATING**

Figure 1.5 shows a spectrometer that uses a diffraction grating to split a beam of light into its constituent wavelengths and enables the angles of the diffracted beams to be measured.

**Figure 1.5**

![Diagram of a spectrometer with a source of light, diffraction grating, and telescope.](image)

a. When the spectrometer telescope is rotated from an initial angle of zero degrees, a spectrum is not observed until the angle of diffraction \( \theta \) is about 50°. State the order of this spectrum.

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b. The angle of diffraction $\theta$ at the centre of the observed beam $B$ in Figure 1.5 is $51.0^\circ$ and the grating has 1480 lines per mm. Calculate the wavelength of the light observed at the centre of beam $B$.

\[
\text{Wavelength} = \ ______________
\]

**Question 4: DOPPLER EFFECT**

A police officer is conducting vehicle speed checks using a radar based monitoring device as shown in Figure 1.5. A car emitting sound of frequency 500 Hz drives past the officer at constant velocity. (Speed of sound in air = $3.40 \times 10^2 \text{ m s}^{-1}$)

**Figure 1.5**

a. At one instant the frequency heard by the officer is 480 Hz. Calculate the speed of the car at this instant.

\[
\text{Speed of car} = \ ______________
\]

Skill level 4

| 4 | 3 | 2 | 1 | 0 | NR |

Skill level 2

| 2 | 1 | 0 | NR |
Question 1: CAR CRASH

The force applied by a seat belt on a crash test dummy is being investigated. The crash test dummy is placed in a car. The car then travels along a test track at a speed of 13.4 m\(\text{s}^{-1}\), collides with a wall and comes to rest as shown on Figure 2.1.

**Figure 2.1**

![Car crash diagram](image)

a. The total mass of the car and dummy is 1 200 kg.

Calculate the change in momentum of the car and dummy in the collision.

\[
\text{Change in momentum} = _________________________
\]

b. The crash test dummy has a mass of 75 kg and is wearing a seat belt. During the collision the dummy travels a distance of 0.48 m at a time of 0.072 s while coming to rest.

Calculate the average force exerted on the dummy by the seat belt.

\[
\text{Average force} = _________________________
\]
Question 2: SIMPLE PENDULUM

A simple pendulum is given a small displacement from its equilibrium position and performs simple harmonic motion as shown on Figure 2.2. (Acceleration due to gravity = 9.81 m/s$^2$)

![Figure 2.2](image)

**Figure 2.2**

equilibrium point

a. State what is meant by simple harmonic motion.

b. A simple pendulum of time period 1.90 s is set up alongside another pendulum of time period 2.00 s. The pendulums are displaced in the same direction and released at the same time.

Calculate the time interval until they next move in phase. Explain how you arrive at your answer.

Time = ___________________________
Question 3: MASS-SPRING SYSTEM

A mass is bouncing (vertically) up and down, between its highest and lowest point, on the end of a spring of negligible mass exhibiting simple harmonic motion as shown on Figure 2.3.

Figure 2.3

a. Describe the energy changes which take place during one complete oscillation of the vertical mass-spring system, starting when the mass is at its lowest point.

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b. Figure 2.4 shows how the total potential energy due to the simple harmonic motion varies with time when the mass-spring system oscillates vertically.

Figure 2.4
i. State the time period of the simple harmonic oscillations that produces the energy–time graph shown in Figure 2.4, explaining how you arrive at your answer.

ii. Sketch a graph on Figure 2.5 to show how the acceleration of the mass varies with time over a period of 1.2 s, starting with the mass at the highest point of its oscillations. On your graph, upwards acceleration should be shown as positive and downwards acceleration as negative. Values are not required on the acceleration axis.

Figure 2.5

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The maximum kinetic energy of the oscillating object is $2.0 \times 10^{-2}$ J. Show that the amplitude of the oscillations of the object is about 40 mm.
Question 4: FLYWHEEL

A flywheel consisting of a solid, uniform disc is free to rotate about a fixed axis as shown in Figure 2.6. The disc has a mass of 16 kg and a radius of 0.30 m.

Figure 2.6

![Figure 2.6](image)

a. Show that the moment of inertia of the flywheel is $0.72 \text{ kg.m}^2$.

b. A mass is attached to the flywheel by a light string as shown in Figure 2.7.

Figure 2.7

![Figure 2.7](image)
The mass is allowed to fall and is found to be travelling at $3 \cdot 0 \text{ m. s}^{-1}$ when the string leaves the flywheel. The flywheel makes 5 further revolutions before it comes to rest.

i. Calculate the angular acceleration of the flywheel after the string leaves the flywheel.

Angular frequency = ________________

ii. Calculate the frictional torque acting on the flywheel.

Torque = ________________

c. A Kinetic Energy Recovery System (KERS) is used in racing cars to store energy that is usually lost when braking.

One of these systems uses a flywheel, as shown in Figure 2.8, to store the energy.

**Figure 2.8**

Data for the KERS flywheel:
- Internal radius $r_i = 0.15 \text{ m}$
- External radius $r_e = 0.20 \text{ m}$
- Mass of flywheel $M = 6.0 \text{ kg}$
- Maximum rate of revolution $= 6 \cdot 0 \times 10^4 \text{ revolutions per minute}$
i. Using the expression

\[ I = \frac{1}{2} M (r_i^2 + r_e^2) \]

Determine the moment of inertia of the flywheel.

ii. Calculate the maximum rotational kinetic energy that can be stored in the flywheel.

Question 5: DRIVING ON BANKED CORNERS

Use the gravitational field strength = 9.80 N. kg\(^{-1}\) (or acceleration due to gravity = 9.80 m. s\(^{-2}\)).

Vasi is driving home from work in her car. At one point she drives around a bend on the road that has a horizontal radius of 90.0 m and banking at an angle of 6.50°. Bends in roads are banked so that cars can travel around them at the same speed as on straight parts without sliding. The mass of Vasi and the car is 995 kg. Assume the friction force acting up or down the slope is zero.

Figure 2.9
a. On the diagram on page 13, draw a free body force diagram to show the reaction force $F_R$, the gravitational force, $F_g$, and the unbalanced force, $F_C$ acting on Vasi’s car. Label all vectors.

b. In terms of the forces acting on the car, explain why the car will travel around the bend.

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Skills level 3
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Skills level 1
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Question 1: DC ELECTRICITY

A battery of negligible internal resistance is connected to lamp P in parallel with lamp Q as shown on Figure 3.1. The *emf* of the battery is 12 V.

**Figure 3.1**

a. Lamp P is rated at 12 V 36 W and lamp Q is rated at 12 V 6 W.
   
i. Calculate the resistance of P.

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   ________________________________________________________________

   Resistance of P = ____________________

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   _____________________________  
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   **Skill level 1**
   
   | 1 | 0 | NR |

   ii. Calculate the resistance of Q.

   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________

   Resistance of Q = ____________________

   _____________________________  
   _____________________________  
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   **Skill level 1**
   
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b. State and explain the effect on the brightness of the lamps in the circuit shown in Figure 3.1 if the battery has a significant internal resistance.

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c. The lamps are now reconnected to the 12 V battery in series as shown in Figure 3.2.

Figure 3.2

![Diagram of a circuit with a 12 V battery and two lamps labeled P and Q.]

State and explain which of the lamps will be brighter assuming that the resistance of the lamps does not change significantly with temperature.

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Question 2: CAPACITOR

The circuit shown in Figure 3.3 contains a battery, a resistor, a capacitor and a switch.

Figure 3.3

The switch in the circuit is closed at time $t = 0$. The graph below shows how the charge $Q$ stored by the capacitor varies with $t$.

![Graph showing charge $Q$ vs. time $t$]

a. Name the physical quantity represented by the gradient of the graph.

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b. i. Calculate the maximum value of the current, in mA, in this circuit during the charging process.

Maximum Current = _______________________

ii. Sketch a graph on the outline axes to show how the current varies with time as the capacitor is charged. Mark the maximum value of the current on your graph.
Question 3: SELF INDUCTANCE

A solenoid of length $l$ and circular cross-sectional area $A$ is wound with a total of $N$ turns of wire is shown on Figure 3.5. The resistance of the wire can be neglected. (Permeability of free space $\mu_0 = 1.26 \times 10^{-6} \ T.m.A^{-1}$)

Figure 3.5

a. Show that the inductance of the solenoid is given by:

$$L = \frac{\mu_0 N^2 A}{l}$$
Question 4: SIMPLE ELECTRIC GENERATOR

Figure 3.6 shows an end view of a simple electrical generator. A rectangular coil is rotated in a uniform magnetic field with the axle at right angles to the field direction. When in the position shown in Figure 3.6 the angle between the direction of the magnetic field and the normal to the plane of the coil is $\theta$.

Figure 3.6

a. The coil has 50 turns and an area of $1.9 \times 10^{-3}$ m$^2$. The flux density of the magnetic field is $2.8 \times 10^{-2}$ T. Calculate the flux linkage for the coil when $\theta$ is 35°.

Flux linkage = ______________

b. The coil is rotated at constant speed, causing an emf to be induced.

i. Give the value of the flux linkage for the coil at the positions where the emf has its greatest values.

Flux linkage = ______________
ii. Explain why the magnitude of the emf is greatest at the values of \( \theta \) shown in your answer to part (b)(i).

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**Question 5: AC ELECTRICITY**

A 55 mH inductor, with internal resistance of 20 \( \Omega \), is connected in series to a 600 \( \mu \)F capacitor as shown on Figure 3.7. The voltage in the circuit is supplied by a 5.0 V signal generator of variable frequency.

**Figure 3.7**

- Show that the impedance of the circuit when the signal generator is set at 60 Hz is 26 \( \Omega \).

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b. What is the current in the circuit when the signal generator is set at 60 Hz?

Current = __________________________

c. Calculate the maximum current of this circuit.

Maximum current = __________________________

d. Draw the graph of current vs frequency for this circuit, including the resonant frequency.
An electron is incident on a hydrogen atom. As a result an electron in the ground state of the hydrogen atom is excited to the \( n = 2 \) energy level. The atom then emits a photon of a characteristic frequency.

**Figure 4.1** shows the lowest three energy levels of a hydrogen atom.

\[
\begin{align*}
n = 3 & \quad \text{energy (eV)} = -1.51 \\
n = 2 & \quad \text{energy (eV)} = -3.41 \\
n = 1 & \quad \text{energy (eV)} = -13.6
\end{align*}
\]

a. i. Calculate the frequency of the photon.

Frequency = ____________________
The initial kinetic energy of the incident electron is $1.70 \times 10^{-18}$ J.

ii. Calculate its kinetic energy after the collision.

\[
\text{Kinetic energy} = \frac{\text{Initial energy}}{2} = \frac{1.70 \times 10^{-18}}{2} = 8.50 \times 10^{-19} \text{ J}
\]

b. When electrons in the ground state of hydrogen atoms are excited to the $n = 3$ energy level, photons of more than one frequency are subsequently released.

i. Explain why are different frequencies possible.

\[
\text{Kinetic energy} = \frac{\text{Initial energy}}{n^2} = \frac{1.70 \times 10^{-18}}{3^2} = 1.70 \times 10^{-19} \text{ J}
\]

ii. Describe how many possible frequencies could be produced.

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\text{Skill level 2}
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Question 2: PHOTOLELECTRIC EFFECT

- Plank’s Constant, $h = 6.63 \times 10^{-34} \text{ J.s}$
- Charge on the electron = $1.60 \times 10^{-19} \text{ C}$
- Mass of electron = $9.11 \times 10^{-31} \text{ kg}$
- Speed of light = $3.00 \times 10^8 \text{ m.s}^{-1}$

a. Experiments based on the photoelectric effect support the particle nature of light. In such experiments light is directed at a metal surface.

i. State what is meant by the threshold frequency of the incident light.

ii. Explain why the photoelectric effect is not observed below the threshold frequency.
Question 3: NUCLEAR REACTIONS

When a $^{235}_{92}U$ nucleus absorbs a slow-moving neutron and undergoes fission one possible pair of fission fragments is technetium $^{112}_{43}Tc$ and indium $^{122}_{49}In$.

- Speed of light $= 3.00 \times 10^8 \text{ m. s}^{-1}$

a. Calculate the energy released, in MeV, when a single $^{235}_{92}U$ nucleus undergoes fission in this way.

Binding energy per nucleon of $^{235}_{92}U = 7.59 \text{ MeV}$

Binding energy per nucleon of $^{112}_{43}Tc = 8.36 \text{ MeV}$

Binding energy per nucleon of $^{122}_{49}In = 8.51 \text{ MeV}$

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Tonga National Form Seven Certificate

PHYSICS

2015

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