Physics

Higher level

Paper 2

2 hours 30 minutes

Instructions to candidates

- Write your session number in the boxes above.
- Do not open the examination paper until instructed to do so.
- Answer all questions
- Answers must be written in the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **physics data booklet** is required for this paper.
- The maximum mark for this examination paper is **[90 marks]**.

1. A student releases a small block of mass 2.0 kg from rest at the top of a smooth frictionless ramp. The block starts from a height of 3.0 m above the ground. At the bottom of the ramp, the block moves horizontally across a rough surface with a constant frictional force of 4.0 N acting against its motion.

(a) Calculate the speed of the block at the bottom of the ramp. [3]

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(b) Determine the kinetic energy of the block at the bottom of the ramp. [2]

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(c) Calculate the distance the block travels on the rough surface before coming to rest. [3]

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(d) State the principle of conservation of energy and explain how it applies to this situation. [2]

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2. An airboat is a water vehicle propelled by a fan blowing a column of air behind the boat. A particular airboat has a total mass of 240 kg and has a fan that blows 16 kg of air per second at 5.0 m s^{-1} relative to the boat.

(a) The airboat is placed on the surface of a lake. Given that the boat floats, find the volume of water displaced by the airboat. The density of water is 1000 kg m^{-3}. [2]

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The fan is turned on and the boat accelerates across the water.

(b) Given that the boat travels 8.0 m in 8.0 s, show that the average resistive force from the water on the boat is approximately 20 N. [4]

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(c) Find the velocity of the air blown by the fan after 8.0 s from the reference frame of the lake. [3]

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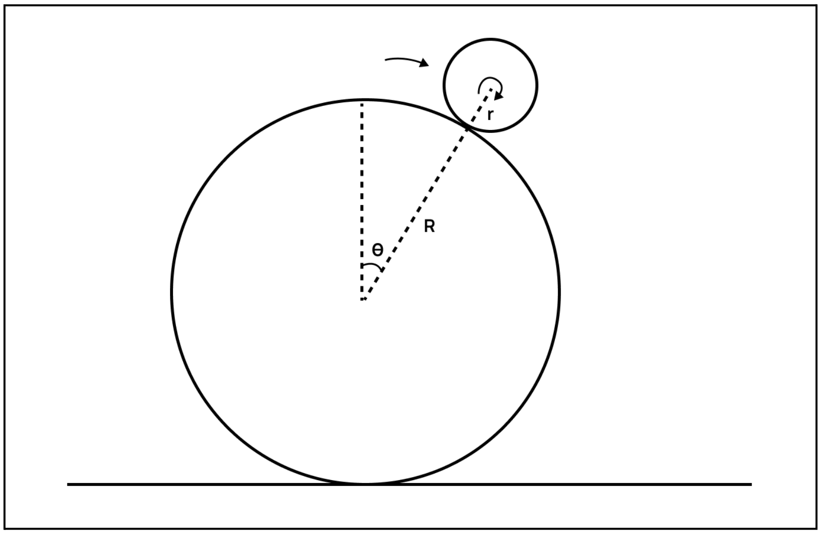
(d) Sketch a graph showing the variation of the **speed** of the air from the reference frame of the lake over time. Precise values are not needed. [3]

3. A small sphere of radius $r = 12\ cm$ rolls off the top of a larger sphere of radius $R = 60\ cm$ from rest as shown in the figure below. Initially, the sphere rolls without slipping. The larger sphere is attached to the ground and does not move.



(a) Show that the linear speed of the center of mass of the small sphere after it has rolled an angle θ on the larger sphere can be expressed as $v = \sqrt{\frac{10}{7}g(R + r)(1 - \cos\theta)}$. The moment of inertia of a sphere is given by $I = \frac{2}{5}mr^2$. [4]

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At a certain angle, the smaller sphere will lose contact with the larger sphere.

(b) Show that this angle is approximately $\theta = 54^{\circ}$. [4]

4. A school decides to participate in the Allay Robotics Competition. The objective of the competition is to score points by launching "tetraballs" to the other side of the field and pushing them under a goal.

The robot the school has built uses a pneumatic flap system to push balls into the goal. The pneumatics system is powered by a cylindrical gas tank 2.50 cm in radius and 15 cm in length. The tank initially stores 0.350 g of air at atmospheric pressure.

(a) Ryan uses an air pump to fill the tank to a pressure of 170 kPa. Find the average outward force acting on the wall of the tank. [2]

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(b) After the tank is filled, its mass increases by 0.210 g. Given that the molar mass of air is approximately 29.0 g mol^{-1}, find the temperature of the tank after it has been filled in °C. [3]

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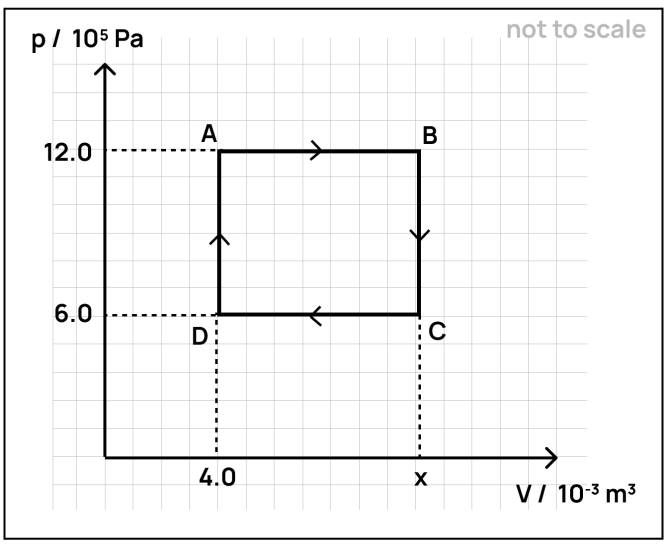
5. A monatomic ideal gas undergoes a rectangular thermodynamic cycle ABCD as shown below:



(a) State whether the cycle does positive or negative work. [1]

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(b) Point A is at the same temperature as point C. Find the volume x during process BC. [2]

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2.0 mol of an ideal gas undergoes a cycle ABCD to power an electric motor.

(c) Find the temperature at B. [1]

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(d) Find the work done by the cycle. [2]

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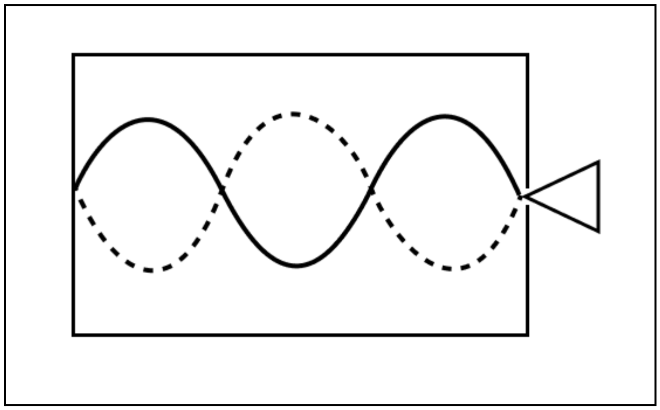
6. A microwave oven functions by reflecting microwave radiation off the metal walls of the oven to form a standing wave, an example of which is shown below.



(a) A particular microwave oven uses microwaves of wavelength 12 cm. If a standing wave at the 5th harmonic is created inside the microwave, find the width of the microwave chamber. [1]

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A microwave heats up food using electromagnetic radiation to induce vibration in water molecules.

(b) Estimate the resonant frequency of a water molecule. [1]

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Two small potato cubes with a mass of 5.0 g each are placed inside a microwave oven. Cube A is placed 6.0 cm away from the oven wall, and cube B is placed 9.0 cm away.

(c) Explain which cube is not heated up when the microwave is turned on. [2]

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(d) The other cube increases in temperature by 30°C. Given that potatoes and water have specific heat capacities of 3350 J kg^{-1} K^{-1} and 4200 J kg^{-1} K^{-1} respectively:

(i) Find the energy transferred to the potato cube. [1]

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(ii) Estimate the amplitude of oscillation of a water molecule in the potato after the temperature increase, given that the mass of a water molecule is approximately 3.0×10^{-26} kg. [3]

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(e) Suggest why it is hazardous to microwave metal. [2]

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7. A spaceship X starts firing a laser beam of wavelength 680 nm at time coordinate t = 0 at an enemy spaceship Y.

(a) Find f_0, the frequency of the laser beam in Spaceship X's reference frame. [1]

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At the same time, a scouting pod is travelling near spaceship X at a speed of 900 km s^{-1} relative to the spaceship.

(b) The scouting pod is travelling towards the laser cannon parallel to the path of the laser. Estimate the wavelength of the laser beam from the reference frame of the scouting pod to 3 s.f. [2]

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Spaceship Y is moving towards Spaceship X at a speed of $v = 0.95c$.

(c) State whether the laser beam will be redshifted or blueshifted. [1]

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(d) Ignoring relativistic effects, state the frequency f' of the laser beam in the reference frame of Spaceship Y in terms of c, v, and f_0. [1]

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(e) Hence, by considering the time dilation of the period of the laser beam,

(i) Show that the frequency of the light seen by Spaceship X is given by $f' = f_0\sqrt{\frac{c+v}{c-v}}$. [3]

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(ii) Find the part of the electromagnetic spectrum the laser beam falls into as seen by Spaceship X. [2]

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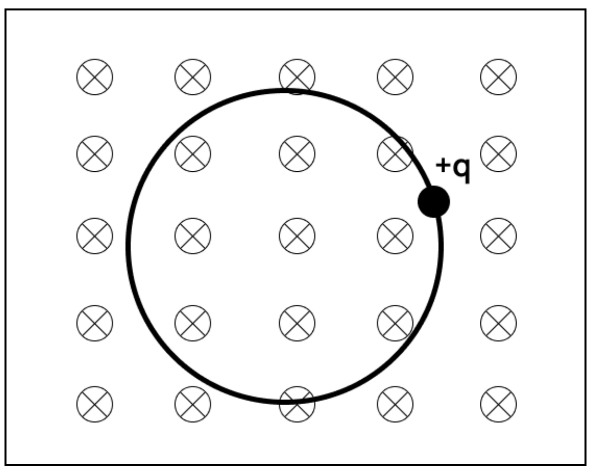
8. A particle of mass m and charge $+q$ moves with constant velocity v in a magnetic field of strength B as shown below.



(a) State whether the particle moves clockwise or anticlockwise. [1]

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(b) Find the radius *r* of the path in terms of q, B, and its momentum p. [2]

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(c) Find the period of the circular motion and outline whether it is dependent on the particle's velocity. [2]

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It is now given that $v > 0.9c$. The momentum of a relativistic particle is given by γmv, where γ is the Lorentz factor.

(d) State the radius *r* of the path in terms of q, B, m, v and γ. [1]

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(e) Find the period of the circular motion and outline whether it is dependent on the particle's velocity. [2]

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(f) A proton is travelling in a circular path in a magnetic field of strength 50 mT. Find the period of motion in the cases where its velocity is:

(i) 100 m s^{-1} [1]

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(ii) 0.99c [1]

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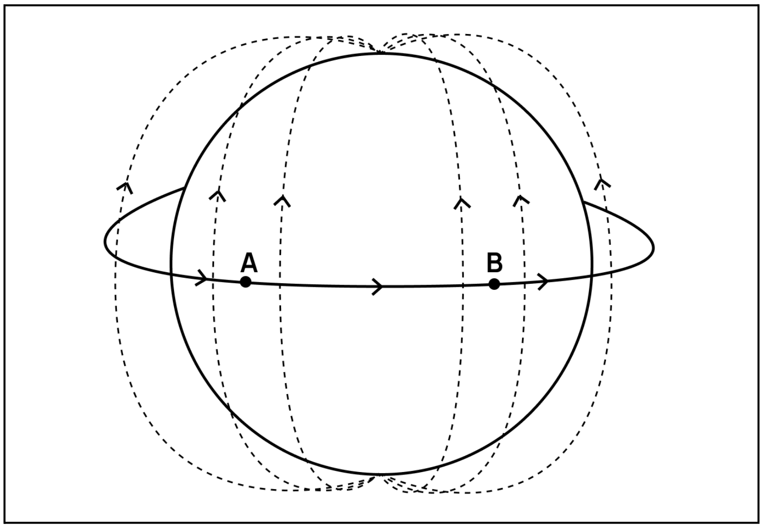
9. Two probes each of mass 400 kg are orbiting eastward around the equator of a neutron star as shown below. The neutron star exerts a northward magnetic field of strength 1.0 T.



(a) Outline the formation of a neutron star. [1]

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(b) The neutron star has a mass of 3.00×10^{30} kg. If the probes orbit at a velocity of 4.04×10^{6} m s^{-1}, find the radius of their orbit. [2]

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Neutron stars emit charged particles and high-energy electromagnetic radiation.
This can ionize atoms near the neutron star.
Probe A is charged to -10.0 C and Probe B is charged to +10.0 C.

(c) Explain what effect this will have on the orbital radius of each probe. [3]

(d) Assuming the orbital velocities stay constant, find the minimum new orbital radii of:

(i) Probe A [3]

(ii) Probe B [2]

10. In a fission reactor, uranium-235 $^{235}_{92}U$ undergoes induced fission to produce caesium-137 $^{137}_{55}Cs$, rubidium-96 $^{96}_{37}Rb$, and several neutrons.

(a) State the number of neutrons emitted by uranium-235 fission. [1]

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(b) Outline the purpose of the moderator in a nuclear fission reactor. [2]

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The following data are given:

Nuclide	Atomic mass / amu
$^{233}_{92}U$	235.043923
$^{137}_{55}Cs$	136.907084
$^{96}_{37}Rb$	95.934284

(c) A particular nuclear plant consumes 7.0×10^{-7} of $^{235}_{92}U$ per second. Find the power, in MW, generated by this nuclear plant. [3]

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(d) Find the mass of water boiled per second by this nuclear plant. The specific latent heat of vaporization of water is 2268 J g^{-1}. [1]

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(e) This boiled water is used to spin a turbine. Explain how this produces electricity for consumers. [3]

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