



Coimisiún na Scrúduithe Stáit
State Examinations Commission

LEAVING CERTIFICATE EXAMINATION, 2023

PHYSICS – HIGHER LEVEL

WEDNESDAY, 21 JUNE – MORNING, 9:30 TO 12:30

Answer **three** questions from **Section A** and **five** questions from **Section B**.

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Relevant data are listed in the *Formulae and Tables* booklet, which is available from the Superintendent.

The 2023 examination papers were adjusted to compensate for disruptions to learning due to COVID-19. This examination paper does not necessarily reflect the same structure and format as the examination papers of past or subsequent years.

SECTION A (120 MARKS)

Answer **three** questions from this section.

Each question carries 40 marks.

1. In an experiment to determine the acceleration due to gravity g , the time t for an object to fall from rest through a distance s was measured. The procedure was repeated for a series of values of s .

The following data were recorded.

s (cm)	40	50	60	70	80	90
t (cs)	29	32	35	38	40	43

- (i) Draw a labelled diagram of the apparatus used in the experiment.
- (ii) Indicate the distance s on your diagram.
- (iii) Describe how the time interval t was measured. (18)
- (iv) Draw a suitable graph to show the relationship between s and t .
- (v) Use the graph to calculate a value for g . (18)
- (vi) The object used was a smooth metal sphere. Explain why. (4)

2. In an experiment to determine the focal length f of a concave mirror, a student first found an approximate value for the focal length. She then measured the image distance v for a series of object distances u .

The following data were recorded.

u (cm)	20.0	30.0	40.0
v (cm)	66.3	31.1	25.2

- (i) How did the student find an approximate value for f ?
- (ii) Why did the student find an approximate value for f ? (12)
- (iii) Draw a labelled diagram of the apparatus used in this experiment. Show u and v on your diagram.
- (iv) Describe how the student determined and measured v .
- (v) Use all of the data to calculate f . (28)
3. In an experiment to determine the wavelength of monochromatic red light, a collimated beam of light was incident perpendicular to a diffraction grating. The diffraction grating had 300 lines per mm. A series of images was observed on a screen placed 75 cm from the grating. The distance between the third order images on the screen was measured. They were 1.04 m apart.
- (i) Draw a labelled diagram of how the apparatus was arranged in this experiment.
- (ii) How were the third order images identified? (15)
- (iii) Calculate the grating constant d .
- (iv) Calculate the wavelength of the red light. (15)
- (v) Describe how the pattern observed on the screen changes when:
- (a) the diffraction grating is replaced with a diffraction grating of fewer lines per mm,
- (b) the red light is replaced with green light,
- (c) the screen is moved further away from the grating. (10)

4. In an experiment to determine the specific latent heat of vaporisation of water, cool water was placed in a copper calorimeter. Dry steam at a temperature of 100 °C was then added to the water.

The following data were recorded.

Mass of calorimeter		65.8 g
Mass of calorimeter + water	before adding steam	111.6 g
	after adding steam	114.3 g
Temperature of water	before adding steam	5.5 °C
	after adding steam	36.4 °C

- (i) Draw a labelled diagram of how the apparatus was arranged in this experiment.

How did the student (ii) cool the water, (iii) dry the steam?

Why did the student (iv) cool the water, (v) dry the steam? (24)

- (vi) Use the data to calculate the specific latent heat of vaporisation of water. (16)

specific heat capacity of water = 4180 J kg⁻¹ K⁻¹; specific heat capacity of copper = 390 J kg⁻¹ K⁻¹

5. A student investigated the variation of current I with potential difference V for a semiconductor diode in forward bias.

The following data were recorded.

V (V)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
I (mA)	0	0	0	0	5	20	70	220

- (i) Draw a circuit diagram for this experiment with the diode in forward bias.

- (ii) Draw a suitable graph to show the relationship between I and V for a diode in forward bias. (21)

- (iii) Is Ohm's law obeyed for this diode? Justify your answer. (6)

The student then investigated the variation of current I with potential difference V for a diode in reverse bias. Several adjustments were made to the circuit.

- (iv) Draw a circuit diagram for this experiment with the diode in reverse bias.

- (v) Sketch a graph to show the relationship between I and V for a diode in reverse bias. (13)

SECTION B (280 MARKS)

Answer **five** questions from this section.

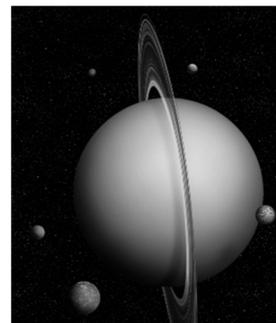
Each question carries 56 marks.

6. Answer any **eight** of the following parts, (a), (b), (c), etc.

- (a) An airplane starts from rest on a runway and reaches a velocity of 290 km hour^{-1} in 33 s. Calculate the acceleration of the airplane in terms of g , the acceleration due to gravity.



- (b) Explain the term solar constant.
- (c) A converging lens of focal length 15 cm is placed in combination with a diverging lens of focal length 5 cm. Calculate the power of the combination.
- (d) Uranus has a mass of $8.7 \times 10^{25} \text{ kg}$ and a radius of 25 400 km. Calculate the acceleration due to gravity on Uranus.
- (e) Draw a diagram to show how a ray of light can be turned through 90° using a $45^\circ\text{--}90^\circ\text{--}45^\circ$ prism.
- (f) State one application of stress polarisation.
- (g) What is meant by potential difference?
- (h) Calculate the power output of a resistor of resistance 3.4Ω when a potential difference of 55 V is maintained across it.
- (i) The peak voltage of an a.c. supply is 311 V. Calculate its rms voltage.
- (j) A proton experiences a force of $4.59 \times 10^{-16} \text{ N}$ when it moves with velocity v perpendicular to a magnetic field of flux density 18.5 mT. Calculate v .
- (k) Explain what is meant by a chain reaction in nuclear fission.
- (l) The equation to describe an emission line spectrum is $hf = E_2 - E_1$. Explain what each of the symbols in this equation stands for.



(8 × 7)

acceleration due to gravity = 9.8 m s^{-2}

7. (i) State Newton's third law of motion.
(ii) Show that $F = ma$ is a special case of Newton's second law of motion.



A force of 6.8 kN is applied to a golf ball at rest by the head of a golf club. The ball has a mass of 45.6 g and the club and ball are in contact for a time of 0.51 ms.

- (iii) Calculate the velocity of the ball immediately after impact. (24)

The velocity of the ball immediately after impact is at an angle of 15° to the horizontal.

- (iv) Draw separate diagrams to show the forces acting on the ball

- (a) during impact,
(b) immediately after impact.

- (v) Calculate the maximum height reached by the ball.

- (vi) Calculate the time it takes for the ball to travel a horizontal distance of 280 m. (24)

A wind blows as the ball travels through the air. The wind has a velocity of 8.2 m s^{-1} east and 3.7 m s^{-1} north.

- (vii) Calculate the magnitude and direction of the velocity of the wind. (8)

acceleration due to gravity = 9.8 m s^{-2}

8. The strings of a guitar can be plucked so that they vibrate at certain frequencies. The guitar and the air inside it also vibrate due to resonance.

(i) What is resonance?

(ii) Describe a laboratory experiment to demonstrate resonance. (15)

The frequency f of a stretched string depends on its length l , tension T and linear density (mass per unit length) μ .



(iii) For each of the following pairs of variables, sketch a suitable graph to show the relationship between them.

(a) f and T

(b) f and l

(c) f and μ

(iv) For each of the following variables, state the effect on the frequency f if the variable is increased by a factor of four.

(a) T

(b) l

(c) μ

(24)

A string is stretched between two fixed points which are 62 cm apart. The string vibrates with a number of different harmonics. The speed of sound in the string is 380 m s^{-1} .

(v) What are harmonics?

(vi) Draw a diagram to show the string vibrating at its third harmonic.

(vii) Calculate the frequency of the string when it is vibrating at its third harmonic. (17)

9. Voyager I and Voyager II are spacecraft that were launched in 1977 to investigate the outer planets of our solar system.



The spacecraft are powered with radioisotope thermoelectric generators. When the spacecraft were launched, each generator contained 4 kg of plutonium–238. Each atom of plutonium–238 has a mass of $3.9529085 \times 10^{-25}$ kg.

- (i) Write a nuclear equation for the alpha decay of plutonium–238.
(ii) Calculate the energy released during each decay of plutonium–238, in MeV. (23)

The energy released by the decay is converted into electrical energy in thermocouples.

- (iii) State the thermometric property of a thermocouple.
(iv) Draw a labelled diagram of the arrangement of a thermocouple. (12)

Plutonium–238 has a half-life of 87.8 years.

- (v) Calculate the rate of decay of the plutonium in each generator in 1977.
(vi) Calculate the year when only 1 kg of the plutonium will remain in each generator.

The Voyager spacecraft are now beyond our solar system and they are maintaining constant velocities.

- (vii) Use one of Newton's laws to explain why the spacecraft maintain constant velocities. (21)

10. The Van de Graaff generator is named after the American physicist Robert J. Van de Graaff, pictured. It is an electrostatic generator that accumulates charge on a hollow metal dome and produces high voltages which can be used in the production of X-rays.



In a Van de Graaff generator, point discharge is used to move charge on to a belt at the lower comb in the generator.

- (i) Describe how point discharge occurs.
- (ii) Describe a laboratory experiment to demonstrate point discharge. (18)

The dome of a Van de Graaff generator has a diameter of 32 cm. A large electric field exists around the dome when it is given a charge of +200 nC.

- (iii) Draw the electric field around the dome.
- (iv) Calculate the electric field strength at the surface of the dome.
- (v) Calculate the force experienced by an electron placed at the surface of the dome. (21)

A voltage of 70 kV is applied across an X-ray tube.

- (vi) Calculate the maximum speed of the electrons produced in the tube.
- (vii) Draw a labelled diagram of an X-ray tube. (17)

11. Metal detectors are used in treasure hunting and in airport security. They operate on the principle of electromagnetic induction. The coil in the detector is supplied with an alternating current.

- (i) Give a detailed explanation of how a current is induced in the metal that is being detected. (12)

The magnitude and direction of an induced emf are determined by Faraday's law of electromagnetic induction and Lenz's law of electromagnetic induction.

- (ii) State Faraday's law of electromagnetic induction.

- (iii) State Lenz's law of electromagnetic induction.

- (iv) Describe a laboratory experiment to demonstrate either one of these laws. (21)

A circular coil of 500 turns and radius 6.0 cm enters a magnetic field moving with a constant velocity of 8 m s^{-1} perpendicular to the field.

The resistance of the coil is 2.3Ω and the magnetic flux density of the field is 4.5 mT.

- (v) Calculate the time taken for the coil to fully enter the field.

- (vi) Calculate the average emf induced as the coil enters the field.

- (vii) Calculate the average current in the coil as it enters the field. (23)



12. Answer **either** part (a) or part (b).

(a) Anti-matter is the most expensive substance on Earth, costing about €65 trillion per gram.

(i) What is anti-matter?

(ii) Who made a mathematical prediction of the existence of anti-matter?

(9)



A positron is an example of anti-matter.

(iii) Write an equation to show the pair production of an electron-positron pair.

(iv) Explain how (a) charge, (b) momentum are conserved in this interaction.

(v) List the fundamental forces, in order of increasing strength, that a positron experiences.

(vi) Name the fundamental force that a positron does **not** experience. (21)

In the Large Hadron Collider researchers are investigating the pair annihilation of a proton anti-proton pair.

(vii) Calculate the wavelength of the electromagnetic radiation produced when a proton and an anti-proton annihilate. (12)

(viii) Hadrons can be classified as baryons or mesons. Distinguish between baryons and mesons.

(ix) State the quark composition of (a) a proton, (b) an anti-proton.

(x) The Large Hadron Collider is an example of a modern particle accelerator. Explain how it differs from the particle accelerator used by Cockroft and Walton. (14)

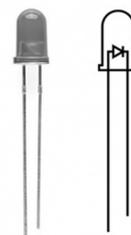
(b) (i) Draw labelled diagrams to show the basic structure of (a) the semiconductor diode, (b) the transistor. (12)

Light emitting diodes and bridge rectifiers are examples of diodes in use.

(ii) Describe the principle of operation of a light emitting diode.

(iii) State one use of a light emitting diode.

(iv) Draw a circuit diagram, including a bridge rectifier and a capacitor, that can be used to convert a.c. to d.c.. (21)



(v) Draw a circuit diagram to show how a transistor can be used as a voltage inverter.

(vi) A voltage inverter is a NOT gate. Draw its truth table. (15)

Electromagnetic relays are sometimes used with transistors.

(vii) Draw a labelled diagram of an electromagnetic relay.

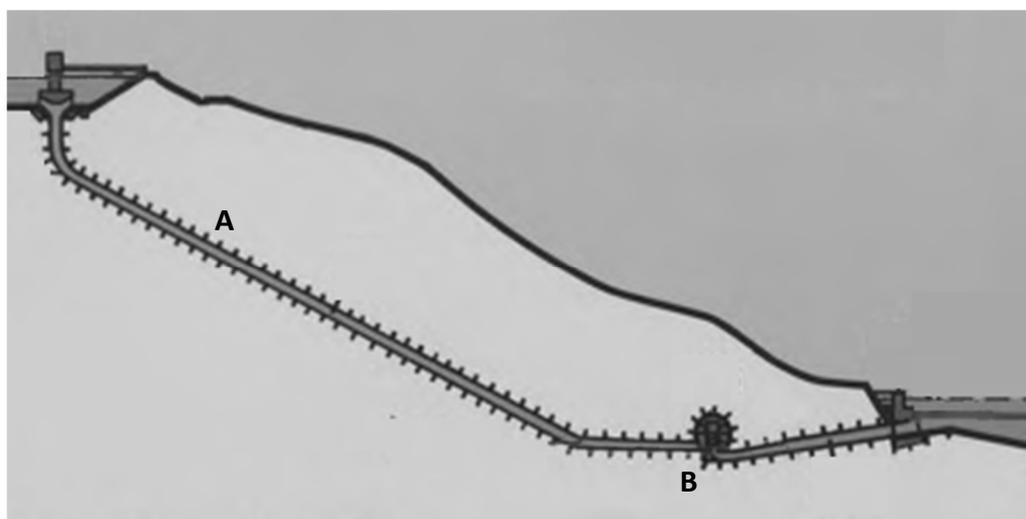
(viii) What is the function of an electromagnetic relay? (8)

13. Read the following passage and answer the accompanying questions.

The electric power grid operates based on a delicate balance between supply and demand. One way to help balance fluctuations in electricity supply and demand is to store electricity during periods of high production and low demand, then release it back to the electric power grid during periods of low production and high demand.

Energy can be stored in a variety of ways, including:

- Pumped storage: e.g. Turlough Hill, a pumped storage power station in Wicklow. It makes use of two water reservoirs, an artificial upper reservoir near the top of a mountain and the naturally occurring corrie lake, Lough Nahanagan, a lower reservoir which is 321 m below. The upper reservoir has a volume of $2.3 \times 10^6 \text{ m}^3$. The two reservoirs are connected by a pipe of length 584 m. A motor pumps water from the lower reservoir to the upper reservoir, using surplus power available at times of low demand. Water is then allowed to fall by gravity from the upper reservoir back into the lower reservoir, passing through turbines attached to electric generators along the way.



- Flywheels: electricity is used to accelerate a large heavy flywheel which stores rotational kinetic energy.
- Batteries: similar to common rechargeable batteries, very large batteries can store electricity.

Adapted from: [epa.gov/energy/electricity-storage](https://www.epa.gov/energy/electricity-storage) and [wikipedia.org/wiki/Turlough_Hill_Power_Station](https://en.wikipedia.org/wiki/Turlough_Hill_Power_Station)

- (i) Assume that the upper reservoir in Turlough Hill is full.
Calculate
- (a) the mass (in kg) of water in this reservoir,
 - (b) the potential energy (in J) stored in this reservoir,
 - (c) the maximum power (in W) that could be generated if the reservoir was fully emptied in 24 hours. (14)
- (ii) State the main energy conversion that takes place (a) as the water flows down through the pipe at position **A** and (b) as the water flows through the generator at position **B**. (7)
- (iii) A motor operates on the principle that a current carrying conductor in a magnetic field experiences a force. Describe a laboratory experiment to demonstrate this principle. (7)
- (iv) A flywheel of diameter 1.4 m rotates with 5000 revolutions per minute.
Calculate
- (a) the period (in s) of the flywheel's motion,
 - (b) the angular velocity of the flywheel,
 - (c) the centripetal acceleration at the circumference of the flywheel. (14)
- (v) A battery is a source of emf. Name two other sources of emf. (7)
- (vi) As we move away from generating electricity using non-renewable sources (e.g. fossil fuels) towards generating electricity using renewable sources (e.g. wind, solar) it is more essential than ever to have energy storage systems such as the ones described in the text. Explain why. (7)

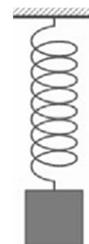
acceleration due to gravity = 9.8 m s^{-2} ; density of water = 0.997 g cm^{-3}

14. Answer any **two** of the following parts, (a), (b), (c), (d).

(a) In 1660 Robert Hooke investigated the elasticity of materials, including springs. His work led to Hooke's law.

(i) State Hooke's law.

A spring has a natural length of 15.0 cm. When a block of mass 500 g is hung from the spring, its length increases to 17.5 cm. The block is then pulled down further, released and begins to oscillate.



(ii) Calculate the elastic constant of the spring.

(iii) Calculate the period of oscillation of the block. (21)

In 1665 Hooke, working as an assistant to Robert Boyle, built the vacuum pump that was used in the experiment that led to Boyle's law.

(iv) Sketch a graph that explains Boyle's law. Label the axes on your graph. (7)

acceleration due to gravity = 9.8 m s^{-2}

(b) A speaker emits a sound of fixed frequency. The speaker is moving at a constant velocity towards an observer. The observer hears a frequency which is 20% greater than the frequency emitted.

(i) Name the effect which causes this increase in frequency.

(ii) Calculate the speed of the speaker.

(iii) Red shift in astronomy is also due to this effect. What does red shift tell us about our universe? (16)

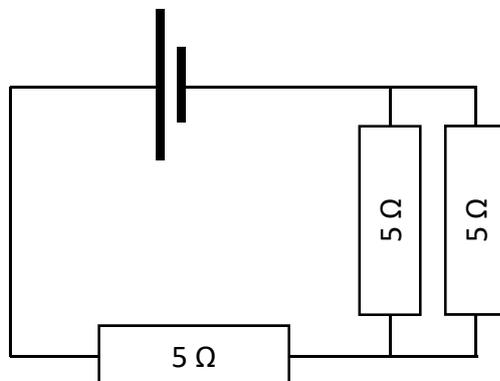
A fixed speaker of power P is emitting sound. At a certain distance from the speaker, an observer can measure both the sound intensity and the sound intensity level due to the speaker.

(iv) Distinguish between sound intensity and sound intensity level.

(v) The speaker of power P is replaced by a speaker of power $4P$. Calculate the increase in sound intensity level measured. (12)

speed of sound in air = 340 m s^{-1}

- (c) A metal wire has length l , resistance R and cross-sectional area A .
- State the relationship between R and A for the wire.
 - Using an appropriate diagram, derive an expression for the effective resistance R_T of two resistors R_1 and R_2 in series. (16)
 - Calculate the total resistance of the circuit shown below.



- Describe how a fourth $5\ \Omega$ resistor could be added to the circuit so as to reduce the total effective resistance of the circuit. (12)

- (d)
 - Distinguish between thermionic emission and the photoelectric effect.
 - Describe a laboratory experiment to demonstrate the photoelectric effect. (15)

Electrons of maximum velocity $0.023c$ are emitted when electromagnetic radiation is incident on a zinc metal plate. Zinc has a work function of $4.3\ \text{eV}$.

- Calculate the frequency of the incident radiation. (13)

Acknowledgements

Images

Images on page 5:	calaero.edu; theguardian.com
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Leaving Certificate Examination – Higher Level

Physics

Wednesday, 21 June

Morning, 9:30 – 12:30