Coimisiún na Scrúduithe Stáit
State Examinations Commission

LEAVING CERTIFICATE EXAMINATION, 2022

PHYSICS – HIGHER LEVEL

WEDNESDAY, 22 JUNE – MORNING, 9:30 TO 12:30

Answer **two** questions from **Section A** and **four** questions from **Section B**.

Do not hand this up.

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State Examinations Commission.

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

SECTION A (80 MARKS)

Answer **two** questions from this section.

Each question carries 40 marks.

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1. A student used a metre stick to investigate the laws of equilibrium for a set of co-planar forces. He found that the weight of the metre stick was 1.2 N and that its centre of gravity was at the 50.6 cm position.

    (*i*)   Describe how the student determined (*a*) the centre of gravity and (*b*) the weight of the metre stick.

    (*ii*) Why was it necessary to determine the centre of gravity of the metre stick?   (10)

    He then applied vertical forces to the metre stick and adjusted them until the metre stick was horizontal and in equilibrium.

    (*iii*) Indicate on a labelled diagram how these vertical forces were applied to the metre stick.

    (*iv*) How was it ensured that the metre stick was in equilibrium?

    (*v*)   What was the principal advantage of ensuring that the metre stick was horizontal?   (12)

    The following data were recorded.

Position on metre stick	22.5 cm	32.1 cm	72.2 cm	81.3 cm
Force (N)	2.85	2.00	3.00	3.40
Direction	upwards	downwards	downwards	upwards

    (*vi*) Calculate the net moment about the 0 cm position.

    (*vii*) Calculate the net vertical force acting on the metre stick.

    (*viii*) Explain how these results verify the laws of equilibrium.   (18)

2. In an experiment to verify Boyle's law, a student measured the length l of a column of air of fixed mass and uniform diameter, at different values of air pressure p.

The following data were recorded.

l (cm)	15.0	20.0	25.0	30.0	35.0	40.0
p (kPa)	360	227	214	178	154	136

(*i*)   State Boyle's law.

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

(*iii*)   Why is it necessary for the column of air to have a uniform diameter?   (18)

(*iv*)   Draw a suitable graph to verify Boyle's law.

(*v*)   Explain how your graph verifies Boyle's law.   (15)

One of the data points is inconsistent with the other data points.

(*vi*)   Which of the data points is inconsistent with the others?

(*vii*)   How did you treat this data point when you drew your graph?   (7)

3. In an experiment to verify Snell's law, a student measured the angle of incidence i and the angle of refraction r for a ray of light as it passes from air into glass. This process was repeated for six different values of i.

The following data were recorded.

i (degrees)	30	40	50	60	70	80
r (degrees)	19	27	32	36	40	44

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

(*ii*)   Describe how the student determined the angle of refraction.   (18)

(*iii*)   Draw a suitable graph to verify Snell's law.

(*iv*)   Use your graph to calculate the refractive index of the glass.

(*v*)   What would be observed if the angle of incidence was zero degrees?   (22)

4. In an experiment to determine the speed of sound in air a student measured the length *l* of a column of air when it was vibrating at its fundamental frequency *f*. This process was repeated for six different values of *f*.

The following data were recorded.

f (Hz)	256	288	320	341	384	480
l (cm)	29.2	25.5	22.6	20.9	18.1	13.7

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

(*ii*) How did the student determine the length of the column of air for a particular frequency? (18)

(*iii*) Draw a graph to show the relationship between *l* and $\frac{1}{f}$.
(Note: the line of best fit on your graph should **not** go through the origin.)

(*iv*) Use your graph to calculate the speed of sound in air.

(*v*) Explain why the line of best fit on the graph does not go through the origin. (22)

5. A student performed a single experiment to (*a*) verify Joule's law, and (*b*) determine the specific heat capacity of olive oil.

An electrical heating coil of resistance 8.5 Ω was immersed in 350 g of olive oil which was at room temperature. A current *I* was allowed to flow through the coil for three minutes and the final temperature *θ* of the oil was determined.

This process was repeated for six different values of *I*.

The following data were recorded.

Room temperature = 17.0 °C

I (A)	1.0	2.0	3.0	3.5	4.0	4.5
θ (°C)	19.2	26.1	36.6	44.4	53.1	62.1

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

(*ii*) How was the mass of the olive oil determined? (15)

(*iii*) Draw a suitable graph to verify Joule's law.

(*iv*) Calculate the slope of your graph.

(*v*) Hence calculate the specific heat capacity of olive oil. (25)

SECTION B (224 MARKS)

Answer **four** questions from this section.

Each question carries 56 marks.

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

(*a*) Iron has a density of 7.87 g cm⁻³. An iron sphere has a mass of 500 g. Calculate the radius of the sphere in cm.

(*b*) Calculate how many electronvolts are in a kilowatt-hour.

(*c*) Draw a labelled diagram to show the forces acting on a piece of wood floating at rest.

(*d*) State the thermometric property of (*i*) a thermocouple, (*ii*) a mercury thermometer.

(*e*) Transverse waves can be polarised. Explain what is meant by polarisation.

(*f*) The sound intensity is 0.18 mW m⁻² at a distance of 3 m in any direction from a source of sound. Calculate the power of the source.

(*g*) Describe how an insulated metal sphere can be charged by induction using a nearby charged rod.

(*h*) A current-carrying wire of length 20 cm is placed in a magnetic field. When a current of 55 mA flows in the wire the maximum force it can experience is 130 μN. Calculate the magnetic flux density of the field.

(*i*) A tungsten cube of side 2 cm has a resistance of 2.8 μΩ. Calculate the resistivity of tungsten.

(*j*) Describe how the Bohr model of the atom explains emission line spectra.

(*k*) What is thermionic emission? Where does it occur in an X-ray tube?

(*l*) Pair annihilation of an electron and a positron occurs in a positron emission tomography (PET) scanner. Write an equation for this annihilation.
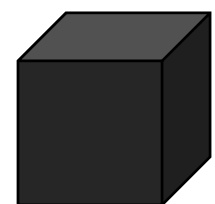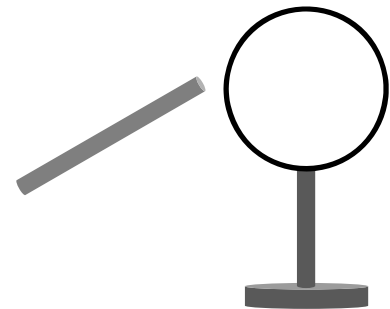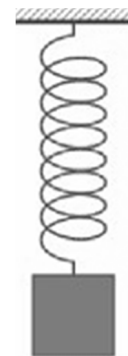
or

Draw the symbol for an AND gate. Write out the truth table for an AND gate. (8 × 7)

7. A spring of natural length 150 mm obeys Hooke's law. When an object of mass 200 g is attached to it, the length of the spring increases to 185 mm.

(*i*) State Hooke's law.

(*ii*) Calculate the elastic constant of the spring.

The object is pulled down until the spring has a length of 200 mm. The object is then released. It moves with simple harmonic motion.

(*iii*) Calculate the period of oscillation of the object.

(*iv*) Calculate the maximum acceleration of the object.

(*v*) What is the speed of the body when it has maximum acceleration? (28)

The object is now detached from the spring and attached to the end of a string of fixed length 11 cm. It is made to rotate in a vertical circle with constant angular velocity and with a period of 0.5 s.

(*vi*) Derive an expression for the linear velocity of an object moving in circular motion in terms of its angular velocity and the radius of the circle.

(*vii*) Calculate (*a*) the angular velocity, (*b*) the linear velocity of the object.

(*viii*) Calculate the minimum tension in the string.

(*ix*) Draw a labelled diagram of the forces acting on the object when the string has its minimum tension. (28)

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

8. Semiconductors are essential in many electrical devices.

(*i*) Distinguish between conductors, insulators and semiconductors.

Semiconductors can be converted into p-type semiconductors and n-type semiconductors by doping.

A p-n junction is used in a diode.
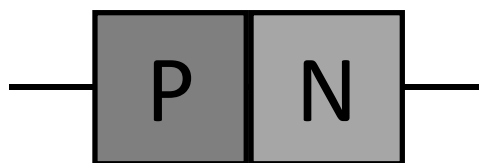
(*ii*) What is meant by doping?

(*iii*) How does p-type doping differ from n-type doping? (18)

A depletion layer exists in a p-n junction.

(*iv*) Describe a depletion layer and explain how it forms.

(*v*) Indicate on a diagram the sections of a p-n junction that are positively charged, negatively charged and neutral. (18)

Associated with every diode is a voltage called its junction voltage. When a variable voltage is applied across a diode held in forward bias, the depletion layer breaks down as the junction voltage is reached.

(*vi*) Draw a circuit diagram to show this arrangement.

(*vii*) Sketch a graph to show the variation of current with voltage for this arrangement. Indicate the junction voltage on your graph.

(*viii*) In many electric circuits a resistor is placed in series with a diode. Explain why this may be necessary. (20)

9. (*a*) A metal sphere of diameter 5 cm holds a charge of –6 µC.

   (*i*) Draw the electric field around the sphere.

   (*ii*) Calculate the electric field strength at a distance of 3 cm from the surface of
   the sphere. (15)

(*b*) A device that is designed to store energy when it holds a specific charge is called a capacitor.

   (*i*) Describe an experiment to demonstrate that a charged capacitor stores energy.

   A parallel-plate capacitor has a dielectric of permittivity ε and its plates have an area of
   overlap A. Voltage V is applied across the plates such that the capacitor stores energy W.

   (*ii*) In terms of some or all of the symbols given, write an expression for (*a*) the charge on
   each plate of the capacitor, (*b*) the distance between the plates. (20)

(*c*) (*i*) Derive an expression for the effective resistance of two resistors in parallel.

   Three resistors X, Y and Z are arranged in a circuit as shown below.
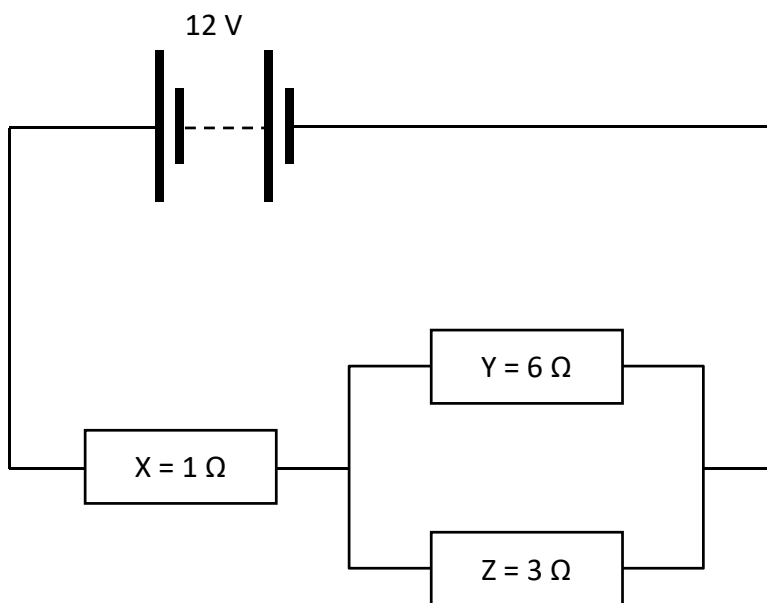
   (*ii*) Calculate the current flowing (*a*) in resistor X, (*b*) in resistor Y. (21)

10. Americium–241, a radioactive substance, is the key component of smoke detectors, where its ionising ability is used to help detect smoke particles. It is produced from plutonium–239 in nuclear reactors.

(*i*)   What is meant by (*a*) radioactivity, (*b*) ionisation?

A nucleus of plutonium–239 can absorb two neutrons to produce plutonium–241. This isotope of plutonium then undergoes beta decay to produce americium–241.

(*ii*)   Write a nuclear equation for the conversion of plutonium–239 into plutonium–241.

(*iii*)   Write a nuclear equation for the conversion of plutonium–241 into americium–241.   (22)

At present, nuclear reactors are fission reactors. Nuclear fusion reactors are not yet viable.

(*iv*)   Outline the differences between nuclear fission and nuclear fusion.

Fission reactors usually contain moderators.

(*v*)   What is the function of a moderator?

(*vi*)   State one example of a moderator.

(*vii*)   Why are nuclear fusion reactors not yet viable?   (17)

Americium–241 undergoes alpha decay in a smoke detector. It has a half-life of 432 years. 241 g of americium–241 contains 6.0×10^{23} nuclei.

A typical smoke detector contains 0.29 μg of americium–241.

(*viii*)   Why are the alpha particles produced in the detector not considered a health hazard?

(*ix*)   Calculate the decay constant for americium–241.

(*x*)   Calculate the activity of the americium in the smoke detector.   (17)

11. The Bronze Age began about 5000 years ago. Archaeologists use physics to help them understand the culture and technology of the Bronze Age.

During the Bronze Age in Ireland, a *fulacht fiadh* was used to heat water, perhaps to cook food.
It contained an open pit which was filled with water. Stones were heated in a fire and the hot stones were placed into the water.

A particular *fulacht fiadh* contained 750 litres of water at an initial temperature of 4 °C. 50 stones were taken from the fire, at a temperature of 280 °C, and placed into the water. The stones had an average heat capacity of 8.5 kJ K^{-1} each.

(*i*)   What is meant by (*a*) heat capacity, (*b*) specific heat capacity?

(*ii*)   Calculate the highest temperature the water could have reached.

(*iii*)   Suggest a way of improving the design of the *fulacht fiadh* to make it more efficient.   (24)

The earliest harps and lyres were produced in the Bronze Age.
Different strings in a lyre may have different lengths, different tensions and different diameters.

(*iv*)   Draw a labelled diagram to represent a stretched string vibrating at its third harmonic.

A 65 cm string of mass 0.21 g is stretched between two points of a lyre which are 34.1 cm apart. It is required to vibrate at a fundamental frequency of 440 Hz.

(*v*)   Calculate the tension that is applied to the string.

(*vi*)   Determine the frequency of the string if the tension is now reduced by a factor of four.   (22)

Archaeologists often use radiocarbon dating to estimate the age of wooden objects. They do this by measuring the ratio of carbon–14 to carbon–12 in a sample and comparing it to this ratio for the carbon in a living tree.

(*vii*)   C–14 and C–12 are both isotopes of carbon. What are isotopes?

(*viii*)   The ratio of C–14 to C–12 in a sample from an archaeological artefact is found to be one quarter the ratio found in a living tree. Is the artefact from the Bronze Age? Justify your answer.   (10)

(for water at 4 °C, 1 litre = 1 kg; specific heat capacity of water = 4180 J kg^{-1} K^{-1}; half-life of carbon–14 = 5730 years)

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

(*a*) In 1932 Ernest Walton and John Cockcroft verified experimentally Einstein's equation that relates mass and energy. They accelerated protons through a potential difference of 70 kV before allowing them to collide with lithium metal.

(*i*) Draw a labelled diagram of their apparatus.

(*ii*) Write a nuclear equation for the interaction between a proton and a nucleus of lithium–7. (21)

The mass of the ^{1}H nuclide is given on page 83 of the *Formulae and Tables* booklet as 1.007825 u.

(*iii*) Convert this mass to kg. (Give your answer to six decimal places.)

(*iv*) Explain the discrepancy between the value you have calculated and the value given for the mass of the proton on page 47 of the *Formulae and Tables* booklet. (6)

Calculate

(*v*) the kinetic energy of the proton as it collided with the metal,

(*vi*) the mass lost (in kg) during the interaction,

(*vii*) the energy produced (in J) during the interaction,

(*viii*) the speed of the alpha particles formed during the interaction. (24)

(*ix*) A proton may be classified as a *hadron*. Explain why.

(*x*) A proton may also be classified as a *baryon*. Explain why. (5)

(*b*)   A moving-coil galvanometer is a device for detecting and measuring electric current.

    (*i*)   What is electric current?

    (*ii*)   Draw a labelled diagram of a moving-coil galvanometer.

    (*iii*)   Describe, with the aid of your diagram, the principle of operation of a moving-coil galvanometer.　　　　(24)

    (*iv*)   Draw a circuit diagram to demonstrate how a galvanometer can be converted into an ammeter.

    (*v*)   Draw a circuit diagram to demonstrate how a galvanometer can be converted into an ohmmeter.

A resistor called a multiplier is used to convert a galvanometer into a voltmeter.

    (*vi*)   A galvanometer has a full scale deflection of 50 mA and a resistance of 0.7 Ω. Calculate the resistance of the multiplier used when this galvanometer is converted into a voltmeter which can read up to 10 V.　　　　(21)

A loudspeaker also contains a moving coil.

    (*vii*) Explain, with the aid of a labelled diagram, how a loudspeaker produces sound.　　　　(11)

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

Europe's greatest scientist during the latter half of the seventeenth century, Christiaan Huygens, was a true polymath. He was a towering figure in the fields of astronomy, mechanics and mathematics, and many of his innovations in methodology, optics and timekeeping remain in use to this day. Among his many achievements, he developed the theory of light travelling as a wave, he invented the mechanism for the pendulum clock, and he discovered the rings of Saturn and its moon Titan – via a telescope that he also had invented.

Huygens is remembered as a problem solver: pragmatic, eclectic and synthetic, sceptical and ready to settle for the most probable rather than hold out for the absolutely certain – in other words, what we expect a scientist to be today.

Adapted from: *'Dutch Light: Christiaan Huygens and the Making of Science in Europe'* (Hugh Aldersey-Williams) Pan Macmillan 2020

(*i*) Diffraction is one of the wave properties of light. What is meant by diffraction? (7)

(*ii*) (*a*) Draw a labelled diagram of an experiment to demonstrate the wave nature of light.

(*b*) What is observed in this experiment?

(*c*) How do the observations demonstrate the wave nature of light? (14)

(*iii*) The eyepiece lens of Huygens' telescope was a converging lens arranged so as to produce a virtual image. Draw a ray diagram to show how a converging lens can produce a virtual image. (7)

(*iv*) The pendulum of Huygens' clock oscillated with a period of 2 s. Calculate the length of this pendulum. (7)

Titan orbits Saturn every 15.9 Earth days. The surface of Titan is 1.16×10^9 m above the surface of Saturn.

(v) Calculate

(*a*) the mass of Saturn,

(*b*) the acceleration due to gravity on the surface of Saturn,

(*c*) the period that Huygens' clock would have on the surface of Saturn. (21)

(*acceleration due to gravity on Earth = 9.8 m s⁻²; radius of Saturn = 58200 km; radius of Titan = 2570 km*)

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

(*a*) (*i*) Distinguish between a vector and scalar.

(*ii*) Draw a labelled diagram of the arrangement of the apparatus in an experiment to find the resultant of two vectors. (10)

An object is released with an initial velocity of 150 m s^{-1} at an angle of 20° to the horizontal.

(*iii*) Resolve the velocity into horizontal and vertical components.

(*iv*) Calculate the magnitude and direction of the velocity of the object after 8 s. (18)

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

(*b*) (*i*) What is the Doppler effect?

(*ii*) Describe, with the aid of labelled diagrams, how the Doppler effect occurs. (16)

Pierre drops a child's toy which emits sound of fixed frequency 500 Hz from the top of the Eiffel tower.

(*iii*) Calculate the frequency Pierre observes after 3 seconds. (12)

(speed of sound in air = 340 m s^{-1};
acceleration due to gravity = 9.8 m s^{-2})
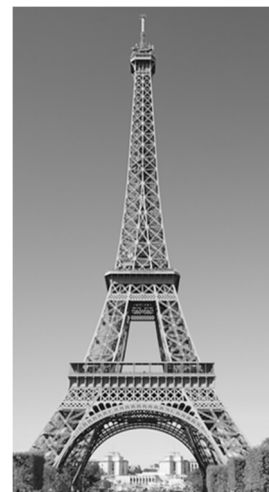
(c)   The explanation of the photoelectric effect by Albert Einstein led to the quantum revolution in physics.

   (i)   Describe a laboratory experiment to demonstrate the photoelectric effect.   (9)

   Light of wavelength 450 nm is incident on a metal that has a work function of 2.4 eV.

   (ii)   Calculate the maximum speed of the emitted electrons.

   It is observed that as the wavelength of the incident light increases, the speed of the emitted electrons decreases and eventually no electrons are emitted.

   (iii)   Explain these observations.   (19)

(d)   (i)   State the laws of electromagnetic induction.   (12)

   A strong magnet is suspended from the end of a string and oscillates in a plane with a constant amplitude.

   (ii)   Describe what is observed when a sheet of copper metal is placed under the oscillating magnet. Explain this observation.

   (iii)   Describe what would be observed if instead of the copper, a sheet of plastic was placed under the oscillating magnet. Explain this observation.   (16)

Leaving Certificate Examination – Higher Level

Physics

Wednesday, 22 June
Morning, 9:30 – 12:30