June 1962

PHYSICS, ADVANCED
SYLLABUS A

Paper I
(THREE HOURS)

Negligently presented or slovenly work will be penalized.

Answer SIX questions including:
(a) at least THREE from Section 1;
(b) at least ONE from Section 2.

Answers to Sections 1 and 2 must be written in different answer-books.

The books must be marked clearly either Section 1 or Section 2 and handed in to the Supervisor separately.

Candidates should wherever possible show by their answers that they have seen or themselves performed experiments on the subjects they are discussing.

For full credit it is not sufficient to obtain correct results to numerical questions; the principles involved and their bearing on the question must be clearly stated.

(Assume that the acceleration due to gravity is 981 cm. sec.\(^{-2}\) or 32 ft. sec.\(^{-2}\) and that 4.18 joules are equivalent to 1 calorie.)

SECTION 1

Answer at least THREE questions from this section.

1. Explain what is meant by the principle of conservation of linear momentum.

Describe, in detail, how you would verify the principle experimentally.

A train is travelling at a constant speed of 60 m.p.h. Find the extra horse-power which must be developed to maintain this speed, when the train is picking up 15,000 lb. of water, from a trough in the middle of the track, at a constant rate over a distance of 440 yards.

1 h.p. is 550 ft.lb. wt. sec.\(^{-2}\).

2. State Hooke’s law and explain what is meant by elastic limit. Show how your statements lead to the definition of Young’s modulus.

With the aid of a labelled diagram describe how you would determine Young’s modulus for nickel in the form of a wire.

Two wires, one of brass and one of steel, are each 5.0 m. long and 0.10 cm. in diameter. They hang vertically 50 cm. apart and support horizontally a light rigid beam. Find the magnitude and position of the mass which must be hung on the beam so that each wire extends 0.10 cm. Assume that Young’s modulus is \(20 \times 10^6\) and \(10 \times 10^1\) dyne cm.\(^{-2}\) for steel and brass respectively.

3. Describe a method for the accurate measurement of the velocity of sound in free air.

Indicate the factors which influence the velocity and show how they are allowed for or eliminated in the experiment you describe.

At a point 20 m. from a small source of sound the intensity is 0.5 microwatt cm.\(^{-2}\). Find a value for the rate of emission of sound energy from the source, and state the assumptions you make in your calculation.

4. Describe, with the aid of diagrams, the nature of the particle motion of a stretched string executing transverse vibrations at (a) the fundamental frequency, (b) the frequency of the first overtone.

A wire clamped at both ends is 100 cm. long, has a mass of 0.60 gm. and is under a tension of 10 kgm. wt. Find the fundamental frequency of transverse vibration. If the wire is held lightly at a point one third of the way from one end, what will be the frequency of transverse vibration?

Explain why the loudness of the sound heard when a
stretched string is set in transverse vibration is enhanced by the use of a sounding board.

5. Describe how you would determine, in your school laboratory, the coefficient of linear expansion of a metal supplied in the form of a rod or tube about 60 cm. long. Indicate the likely experimental error in the measurements made and hence deduce the maximum possible percentage error in the final result.

A silica rod has a diameter of 0.75 cm. at 20° C. and just fits into an aluminium tube at this temperature. Find the temperature at which the cross-sectional area of the space between the rod and tube is 0.50 mm.². The coefficients of linear expansion of silica and aluminium are 0.50 × 10⁻⁵ and 25.5 × 10⁻⁵ deg.⁻¹ C. respectively.

6. (a) Summarize the characteristics of radiant heat and describe how you would show that good reflectors are poor emitters.

(b) A copper calorimeter fitted with a heating coil has a thermal capacity of 5.0 cal. deg.⁻¹ C. and contains 120 cm.³ of a liquid of density 0.80 gm. cm.⁻³. A current of 2.00 amp. is passed until an equilibrium temperature is reached, and the resistance of the coil is then 3.00 ohm. The current is switched off and the initial rate of cooling is found to be 2.20 deg. C. min.⁻¹. Calculate the specific heat of the liquid.

If in this experiment the equilibrium temperature of the calorimeter was 52° C. and the room temperature was 12° C., what current would be required to maintain the same equilibrium temperature for a room temperature of 17° C? Assume that Newton's Law of Cooling applies.

7. Describe a mechanical method of finding the number of units of mechanical energy which are equivalent to 1 unit of thermal energy. Point out two limitations of the method.

A beam of 10¹⁶ protons per second strikes a metal target which is cooled by a steady stream of oil flowing through it. When steady conditions have been reached it is found that the difference in temperature between inflowing and outflowing oil is 2.5 deg. C. Find the mass of oil flowing through the target per second. Indicate any assumptions you make.

Use the following data:
velocity of protons = 10⁵ cm. sec.⁻¹,
mass of proton = 1.67 × 10⁻²⁴ gm.,
specific heat of oil = 0.55 cal. gm.⁻¹ deg.⁻¹ C.

SECTION 2

(Answers to be written in a separate answer-book.)

Answer at least ONE question from this section.

8. (a) State Newton's law of gravitation.

Newton tested this law by comparing the gravitational attraction at the earth's surface with the attraction of the moon by the earth. Show that such a comparison leads to an expression for the distance D of the moon from the earth in terms of the acceleration g due to gravity at the earth's surface, the radius R of the earth, and the period T of the moon round the earth. State what assumptions you make in your derivation.

(b) A small hole is drilled at each of three widely separated points which are near the edge of an irregularly shaped plane lamina. Describe, with the necessary theory, the experiment you would perform to determine the moment of inertia of the lamina about an axis which passes through one of the holes and is perpendicular to the plane of the lamina.

9. The volume rate Q of orderly flow of a liquid at constant temperature through a horizontal capillary tube of radius a and length l when a pressure difference p exists between the ends of the tube, is expressed by

\[ Q = k \pi a^4 \sqrt{\frac{p}{\mu}} \]

where k is a constant depending only on the liquid, and \( G = \frac{p}{\mu} \). Describe the apparatus you would use and the measurements you would make to verify this form of dependence of Q on \( a \), and on \( G \). If, for a given tube, p is varied over a wide range, state and explain what results you would expect to get.
Two horizontal capillary tubes $A$ and $B$ are of length 50 and 100 cm., and of internal diameter 0.10 and 0.20 cm., respectively. They are held end to end by a tight rubber sleeve. If water enters $A$ under a pressure head of 10 cm. and leaves $B$ at atmospheric pressure, what is the pressure head at the junction of $A$ and $B$?

10. Explain how a centigrade temperature scale can be established. Why would you not necessarily expect the temperature of a body as measured by scales established with different types of thermometer to agree?

Describe the thermometer you would use, and the procedure you would employ, for measuring a rapidly changing temperature. Give reasons for your choice.

11. Distinguish between adiabatic and isothermal changes. Explain how you would attempt to achieve each type of change in experiments with gases.

A fixed mass of an ideal gas whose principal specific heats have a ratio $\gamma$ of 1.67 occupies 200 cm.$^3$ at 31° C. and at one atmosphere pressure. It is allowed to expand adiabatically until the volume is 300 cm.$^3$, after which it is kept at constant pressure until the temperature returns to 31° C. Calculate (a) the pressure and temperature after the adiabatic expansion, (b) the final volume.

Explain why the value of $\gamma$ exceeds unity.

12. Answer the following questions with particular reference to the physical principles involved:

(a) How is hoar frost formed?

(b) Draw ray diagrams to show how light travels through drops of water in order to form primary and secondary rainbows. In what ways do these bows differ?

(c) Why is the setting sun sometimes red?

(d) Why, very occasionally, is it possible near the sea to see an inverted image of a ship in the sky?

June 1962

PHYSICS, ADVANCED

SYLLABUS A

Paper II

(THREE HOURS)

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Answer SIX questions including:

(a) at least THREE from Section 1;
(b) at least ONE from Section 2.

Answers to Sections 1 and 2 must be written in different answer-books.

The books must be marked clearly either Section 1 or Section 2 and handed in to the Supervisor separately.

Candidates should wherever possible show by their answers that they have seen or themselves performed experiments on the subjects they are discussing.

For full credit it is not sufficient to obtain correct results to numerical questions; the principles involved and their bearing on the question must be clearly stated.

**Section 1**

Answer at least THREE questions from this section.

1. In what circumstances is the deviation $D$ of a ray of light transmitted by a prism related to the refracting angle $A$ and the refractive index $\mu$ of the material of the prism by

$$
\sin \left( \frac{1}{2} (D + A) \right) = \frac{\sin \frac{1}{2} A}{\mu}.
$$

State the purpose of 'levelling the table' of a prism spectrometer before making measurements. Describe and explain a
method for measuring the angle of the prism after all preliminary adjustments have been made.

Parallel light is incident on the face $AB$ of an equilateral prism $ABC$ set up as in a spectrometer. What is (i) the angle of incidence of rays which just fail to emerge from the face $AC$, (ii) the total deviation of these rays which now emerge from the face $BC$? The refractive index of the glass for the light used is 1.64.

2. What is meant by (a) the optical centre, (b) a principal focus of a thin lens?

Light from a distant object passes through a thin converging lens of focal length 18 cm. and then through a coaxial thin diverging lens of focal length 6 cm. Find the position and nature of the final image formed when the separation of the lenses is (i) 10 cm., (ii) 14 cm.

State a practical application of each of these arrangements and for one of them draw a diagram showing the paths through the lenses of two rays from a non-axial point on the object.

3. What is Huygens' principle?

Draw and explain diagrams which show the positions of a light wave front at successive equal time intervals when (a) parallel light is reflected from a plane mirror, the angle of incidence being about $60^\circ$, (b) monochromatic light originating from a small source in water is transmitted through the surface of the water into the air.

Describe an experiment, and add the necessary theoretical explanation, to show that in air the wave-length of blue light is less than that of red light.

4. Define electric intensity and potential at a point in an electric field and state the connection between them.

Derive an expression for the capacitance of an isolated conducting sphere. It may be assumed that, when such a sphere is charged, the electric intensity at points outside the sphere is equal to that which would be produced by the entire charge placed at the centre with no sphere present.

An isolated conducting sphere is surrounded by air which becomes conducting when the potential gradient at any point exceeds a certain value. Explain how the maximum potential to which the sphere may be raised depends on the radius. If, for a sphere of radius 50 cm., the maximum potential is $9 \times 10^3$ volt calculate the potential gradient for breakdown.

5. Describe the experimental procedures you would use to compare two resistances which are (a) both of the order of $10^3$ ohm, (b) both of the order of $10^4$ ohm. Explain why a Wheatstone bridge arrangement would not be useful in these experiments.

6. State the laws of electromagnetic induction and explain the working of an electrical transformer with an iron core in terms of these laws.

Mention two reasons for loss of energy in a transformer and describe how these losses are minimized in an efficient transformer.

Draw and explain a diagram showing an electrical circuit for operating an X-ray tube, assuming an A.C. mains supply to be available.

7. Describe (a) an experiment for obtaining a current/voltage graph for a 36W 12V tungsten filament lamp, (b) an experiment for obtaining current/voltage graphs for a diode valve for different filament temperatures. In describing each experiment refer to a circuit diagram and specify suitable magnitudes of components and ranges of instruments.

Illustrate and explain the form of the graphs you would expect to obtain.

Answer at least ONE question from this section.

8. Describe the structure and mode of operation of (a) a microphone, (b) a loudspeaker.

A small loudspeaker emits sound at constant frequency. Calculate (i) the difference in intensity levels (in decibels) at
points $X$ and $Y$ which are respectively 4 metres and 5 metres from the source, (ii) the phase difference between the air vibrations at these points if the frequency is 200 c/s, and the velocity of sound is 340 metre sec.$^{-1}$.

9. Define the terms **lumen, lux**.
With the aid of a labelled ray diagram, describe the optical arrangements in a projection lantern.

If 20% of the light from a 100 c.p. lamp is distributed uniformly over a circular area 2 metres in diameter on a screen, find the illumination at any point within the circle.

10. (a) Explain the coloured appearance of a thin film of oil floating on water when it is seen in daylight.

(b) Describe how you would produce a diffraction pattern using a thin wire. Account for what is observed.

11. Explain the meaning of the term **root-mean-square current** as used in reference to alternating currents.

An alternating current passes through a resistance $R$ and an inductance $L$ of negligible resistance arranged in series. Explain why the sum of the A.C. voltages measured separately across $R$ and $L$ is more than that across the combination.

If a 50 c/s 50V R.M.S. supply of sine-wave form and a number of identical high resistances (of negligible inductance) are available, describe how you would perform experiments with a cathode-ray oscillograph:

(a) to test the linearity of the $Y$ deflection with applied voltage and to find the deflection per volt,

(b) to calibrate the time-base frequency control up to 500 c/s in multiples of 50 c/s.

12. What is meant by the **half-value period (half-life)** of a radioactive material?

Describe how the nature of $\alpha$-particles has been established experimentally.

The half-value period of the body polonium-210 is about 140 days. During this period the average number of $\alpha$-emis-

sions per day from a mass of polonium initially equal to 1 microgram is about $12 \times 10^9$. Assuming that one emission takes place per atom and that the approximate density of polonium is 10 gm.cm.$^{-3}$, estimate the number of atoms in 1 c.c. of polonium.

June 1962

**PHYSICS SCHOLARSHIP**

(THREE HOURS)

Negligently presented or slovenly work will be penalized.

Answer FOUR questions as follows:

(a) Question 1 and ONE other question from Section 1;

(b) Question 5 and ONE other question from Section 2.

Answers to Sections 1 and 2 must be written in different answer-books.

The books must be marked clearly either Section 1 or Section 2 and handed in to the Supervisor separately.

For full credit it is not sufficient to obtain correct results to numerical questions; the principles involved and their bearing on the question must be clearly stated.

( Assume that the acceleration due to gravity is 981 cm. sec.$^{-2}$; 1 cal. = 4.18 joules; standard atmospheric pressure is 1.01 $\times$ 10$^6$ dyne cm.$^{-2}$; the density of air at S.T.P. is 1.29 $\times$ 10$^{-3}$ gm. cm.$^{-3}$; the permittivity of free space is 8.85 $\times$ 10$^{-12}$ farad metre$^{-1}$; the thermal conductivity of copper is 0.92 cal. cm.$^{-1}$ sec.$^{-1}$ deg.$^{-1}$ C.$^{-1}$; the viscosity of water at 4$^\circ$ C. is 0.016 gm. cm.$^{-1}$ sec.$^{-1}$; the velocity of light is 3.0 $\times$ 10$^{14}$ cm. sec.$^{-1}$; the latent heat of vaporization of steam is 540 cal. gm.$^{-1}$.)
Answer Question 1 and ONE other question from this section.

1. Answer THREE of the following:

(a) The bob of a simple pendulum describes a circle in a horizontal plane and the string makes an angle $\theta$ with the vertical. Calculate the periodic time of the steady motion under these conditions and compare it with that of the normal oscillations of small amplitude of the same pendulum moving in a vertical plane.

(b) A chemical reaction, with the rapid evolution of gas, takes place in a beaker. Describe with the aid of a sketch-graph the readings obtained, as the reaction proceeds, from a continuously-reading balance which carries the beaker and its contents.

(c) Electrons are accelerated from a cathode to an anode in a hydrogen-filled discharge tube in which the electrodes are a pair of parallel plates separated by a small distance $d$ cm. Assuming that each electron makes a new electrons by ionization per centimetre of path throughout its motion, show that the number $n$ of electrons reaching the anode per second is related to the number $n_0$ leaving the cathode per second by the equation

$$n = n_0 \exp (ad).$$

Indicate factors which might increase the electron multiplication predicted by the above equation.

(d) A wire loop is mounted rigidly in a horizontal plane. A bar magnet (with its N-pole downwards) falls through the loop. Describe, with the aid of sketch-graphs, the direction and magnitude of the changes in the loop, and also the variation with time of the acceleration of the bar magnet.

2. Explain what is meant by the statement that a liquid displays viscosity, and show how this property is described in terms of a coefficient of viscosity.

Under conditions of streamline flow a sphere of radius $a$ moving with velocity $v$ through a liquid whose coefficient of viscosity is $\eta$ experiences a viscous drag of magnitude $6\pi \eta a v$. Assuming that these conditions apply, derive an expression for the velocity of ascent of a small spherical air-bubble through a liquid of density $\sigma$.

An air-bubble rises vertically through water at $4^\circ$ C. Compare its instantaneous velocity of ascent just below the surface with that at a depth of 200 cm. below the surface if its diameter at this depth is 2 mm.

3. Give a critical account of the capillary rise method of measuring the surface tension of a liquid and explain what considerations you would take into account in deciding what tube diameter to use. What difference, if any, does it make to your experimental procedure if the capillary tube has a non-uniform bore, and why?

If the surface area of a given volume of water were caused to increase indefinitely, a film of minimum thickness would be reached beyond which any further stretching would result in the destruction of the film. By comparing the physical phenomena involved in this process with those involved when water is heated to its boiling point at normal pressure, deduce the order of magnitude of the diameter of the water molecule if the energy required to increase the surface area of a given volume of water by 1 cm.$^2$ under isothermal conditions at $15^\circ$ C. is approximately 117 ergs.

4. The base of a crystal in the form of a cube of side 2 cm. with polished faces is held rigidly in a bath of liquid of refractive index 1.3 (independent of temperature). A plano-convex lens is then held rigidly in the liquid above one face of the cube and Newton’s rings are formed between the crystal and the curved part of the lens with sodium light $\lambda = 5,890 \times 10^{-8}$ cm. For a change of temperature of 10 deg. C., ten dark rings pass a given point of observation.

On repeating the experiment along the other two principal axes of the cube, a change in temperature of 10 deg. C. pro-
duces shifts of 10 and 20 dark rings respectively. Find the coefficient of linear expansion in a direction joining two diagonally opposite corners of the crystal.

Draw a diagram of a suitable experimental apparatus for measuring the coefficient of linear expansion of a crystal in the above manner.

SECTION 2

Answers to be written in a separate answer-book.

Answer Question 5 and ONE other question from this section.

5. Answer THREE of the following:

(a) A particular spectrum line of hydrogen has a wavelength of 4861.37 Å, when measured in the laboratory. In the spectrum of light emitted by a star it appears as a broadened line extending from 4861.63 Å to 4861.87 Å. If it is assumed that the line as emitted on the star has a width less than 0.01 Å, what conclusions might you draw about the motion of the star?

(b) In iron ships of old-fashioned design it sometimes happened that single cables carrying D.C. were used to provide power for lighting and heating in various parts of the ship. In such a case if a cable carrying 150 amps D.C. is brought along the centre of the ship and the ship’s compass is 10 metres directly above the cable, find the maximum error in the compass reading assuming the horizontal component of the earth’s field to be 0.18 oersted (14.4 ampere turns metre⁻¹). Why does the actual error differ from the calculated maximum?

(c) The electron beam of an X-ray tube delivers 1 kW of power to the copper anode over an area 10 mm by 1 mm. The anode is 1 mm thick and is cooled by a water jacket supplied directly from the water main at 15° C. If the water outflow temperature is 30° C, calculate the rate of flow of cooling water you would require and the hot surface temperature of the anode in these conditions, neglecting the sideways flow of heat.

(d) A man carrying a microphone walks towards a smooth high vertical wall in a direction normal to the wall. A distant siren, which is sounding a continuous note of 1,000 c/s, is placed directly behind him. Describe and explain the microphone response he would obtain. If the displacement amplitude of the sound wave arriving at the wall is 0.5 × 10⁻² cm and at a point 2 metres from the wall at a particular instant the displacement is zero, find the magnitude of the displacement at this point 1 1/2 sec. later. The velocity of sound in free air is 330 m. sec⁻¹. Derive any formula you use in calculating the result.

6. Derive and discuss an expression for the couple exerted on a soft iron needle of length l and uniform cross-sectional area A placed at an angle θ to a uniform horizontal magnetic field B. Assume that the iron has a constant susceptibility k.

If the needle is suspended horizontally by a fibre of torsional constant c so that there is no twist in the fibre when the needle is perpendicular to the magnetic field, for what values of the torsion in the suspension is the resultant couple on the needle zero, assuming the earth’s field to be negligible? Show how these values may be found graphically and discuss the dependence of the number of possible values on the magnitude of the constant c.

7. Derive an expression for the energy of a parallel plate condenser of capacitance C (plate area A) charged to a potential V when the plates are separated by a material of dielectric constant (relative permittivity) K and of thickness d.

The plates of a parallel plate condenser are fixed vertically and the space between them is filled by a slab of material of dielectric constant K, which is able to move freely in a vertical direction. The condenser is first charged to a potential V with the dielectric fixed in position between the plates and then isolated, after which the slab is released and allowed to
find its equilibrium position. If in this position the slab projects below the plates to a distance \( h \), derive the condition of equilibrium and the frequency of small oscillations about the equilibrium position. (The amplitude of oscillation is assumed to be small compared with \( h \).)

8. Explain what you mean by the term electromagnetic spectrum. Show, with the aid of a diagram with wavelength indicated, how this spectrum is commonly divided into various regions. Indicate briefly the physical processes involved in the production of the radiations of the different regions.

Select two distinct regions of the spectrum (outside the visible region) and suggest for each a method of accurately determining the wavelengths of the radiations. Describe one of the methods.