**The Handbook of Mathematics, Physics and Astronomy Data is provided**

KEELE UNIVERSITY

EXAMINATIONS, 2010/11

Level II

Wednesday 12$^{th}$ January 2011, 16.00-18.00

PHYSICS/ASTROPHYSICS

PHY-20027

OPTICS AND THERMODYNAMICS

**Candidates should attempt to answer FOUR questions.**

**NOT TO BE REMOVED FROM THE EXAMINATION HALL**

1. (a) Show that for a thin lens:

$$\frac{1}{s_o} + \frac{1}{s_i} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right),$$

where $n$ is the refractive index of the lens. The front and back radii of the lens surfaces are $R_1$ and $R_2$ respectively; $s_o$ and $s_i$ are the object and image distances from the lens. [40]

(b) A white light point source is placed along the optical axis of a convex lens at 0.4 m away from the lens. The image of this source is projected on the other side onto a white screen. A red image of the source is found at 0.6 m away from the lens. The refractive indices of the lens for red and blue light are 1.52 and 1.54 respectively. What is the distance of the blue image of the source from the lens? [40]

(c) Explain briefly the advantages of reflecting telescopes over refracting telescopes. [20]

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2. (a) Describe with a suitable diagram the operation of the Michelson interferometer. [30]

(b) A Michelson interferometer is set up such that circular fringes are observed when a monochromatic light source is used. Explain what happens when the mirror distance is reduced through the point of coincidence and beyond. [20]

(c) Show that the intensity of the fringe pattern for the Michelson interferometer when used with a monochromatic light source is given by:

$$I = I_o \cos^2\left(\frac{\delta}{2}\right),$$

where $\delta$ is the phase difference between the beams and $I_o$ is the maximum intensity. [20]

(d) A thin sheet of fluorite of refractive index 1.434 is inserted normally in one of the beams of a Michelson interferometer. Using light of wavelength $\lambda = 589\,\text{nm}$, the fringe pattern is found to shift by 35 fringes. What is the thickness of the sheet? [30]

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3. (a) Explain the terms *plane polarised light* and *circularly polarised light.* [20]

(b) Explain how polarised light is produced from unpolarised light in the following physical phenomena:

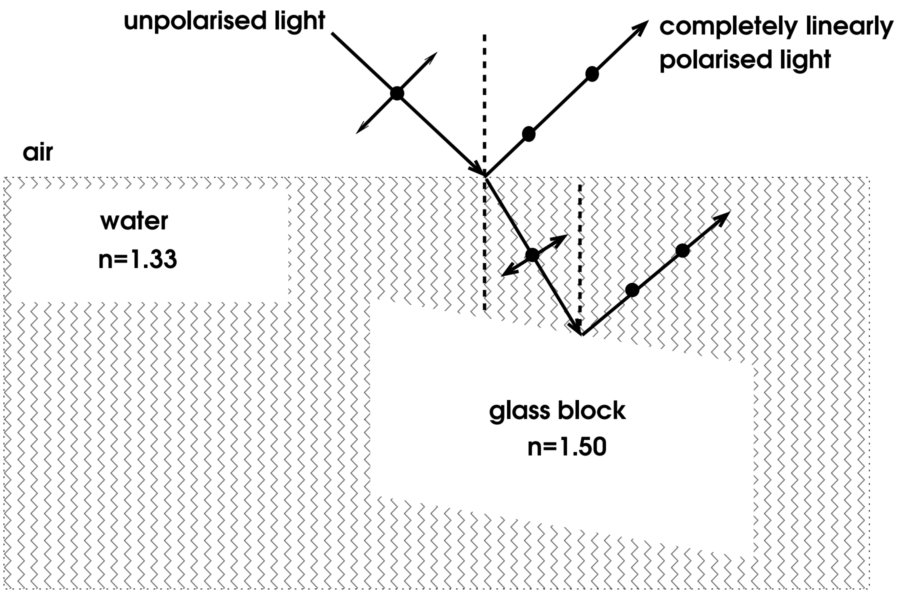
i. birefringence; [15]

ii. dichroism. [15]

(c) Unpolarised light is incident on a water surface ($n = 1.33$) at such an angle that the reflected light is completely linearly polarised, as shown in the figure below.

i. What is the angle of incidence? [15]

ii. The light refracted into the water is intercepted by the top flat surface of a block of glass ($n = 1.50$). The light reflected from the glass is completely linearly polarised. What is the angle between the glass and the water surface? [15]




(d) Derive the state of polarisation of the wave described by:

$\vec{\mathbf{E}} = E_0 \cos(\omega t - kz)\, \hat{\mathbf{i}} - E_0 \sin\left(\frac{\pi}{2} - (\omega t - kz)\right) \hat{\mathbf{j}}$ [20]

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4. A system consists of 2 mole of helium, which has initial volume of $1\,\mathrm{m}^3$ and temperature of $300\,\mathrm{K}$. The gas is taken around the following reversible cycle:

[A]: the volume is doubled adiabatically;

[B]: then, the volume is returned to its initial value, at constant pressure;

[C]: then, the pressure is returned to its initial value, at constant volume.

(a) Sketch and clearly label the $P$–$V$ diagram for this cycle. [10]

(b) What is the change of internal energy over the cycle? Explain your answer. [10]

(c) Calculate

i. the heat absorbed in each of the steps [A]–[C]; [30]

ii. the work done on the gas during each of the steps [A]–[C]; [30]

iii. the efficiency of the engine. [20]

[N.B. The molar specific heat at constant volume for helium is $C_V = 3R/2$, where $R$ is the gas constant.]

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5. (a) Explain, with the aid of a sketch, what is meant by *free expansion* of a gas. [20]

(b) Use the First Law of Thermodynamics to show that the change of internal energy for free expansion is zero. [15]

(c) Hence, show that the internal energy of an ideal gas must depend only on temperature $T$. [35]

$$\left[\text{N.B.} \quad dF = \left(\frac{\partial F}{\partial x}\right)_y dx + \left(\frac{\partial F}{\partial y}\right)_x dy \right]$$

(d) A system consisting of $10^{34}$ mole of an ideal gas undergoes free expansion, from an initial volume $10^{37}\,\mathrm{m}^3$ to a final volume $10^{50}\,\mathrm{m}^3$. Writing the First Law of Thermodynamics in the form

$$dU = T\,dS - P\,dV$$

in the usual notation,

i. what is the change of entropy for the system? [20]

ii. what is the change in entropy for the surroundings? [5]

iii. what is the change of entropy for the "Universe"? [5]

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6. (a) The Clausius–Clapeyron equation for a phase change is given by

$$\frac{dP}{dT} = \frac{L}{T\,\Delta V}\,.$$

Give a physical interpretation of this equation. [20]

(b) Show that, to a good approximation, the Clausius-Clapeyron equation for vapourization of one mole of a substance may be written as

$$\frac{dP}{dT} = \frac{LP}{RT^2}$$

where $R$ is the gas constant. [20]

(c) Hence show that the vapour pressure can be expressed as

$$P(T) = P_0 \;\exp\left[-\frac{L}{RT}\right]$$

where $P_0$ is a constant. [20]

(d) Under normal atmospheric pressure, water boils at 100 °C. Calculate the value of $P_0$. [20]

(e) At the top of the mountain Chomolungma (9 km altitude) the atmospheric pressure is approximately $3.6 \times 10^4$ Pa. Calculate the temperature at which water boils at the summit of Chomolungma. [20]

[N.B. The latent heat of vapourization of water around the boiling point is $2257\,\mathrm{kJ\,kg^{-1}}$.]