KEELE UNIVERSITY

DEGREE EXAMINATIONS 2009

Level 2 (PRINCIPAL COURSE)

Friday 16th January 2009, 13:00 – 15:00

PHYSICS

PHY-20027

OPTICS AND THERMODYNAMICS

Candidates should attempt to answer FOUR questions,
TWO from section A and TWO from section B of the paper.

Tables of physical and mathematical data may be obtained from the invigilator.

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SECTION A: OPTICS (Answer TWO questions)

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

$$\frac{1}{S_o} + \frac{1}{S_i} = (\mu - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

where μ is the refractive index of the lens. The front and back radii of curvature 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 thin convex lens L with equal radii of curvature is placed in front of a plane mirror M as shown in figure 1a. When the object distance from the lens is 0.1m, the image I of the object O is coincide with object as shown in figure 1a. This distance increases to 0.15m when the gap between the thin lens and the mirror is filled with water as shown in figure 1b.

i. Sketch a ray diagram to illustrate the image formation in figure 1a. [10]

ii. Calculate the radius of curvature of the thin convex lens. Assume that the refractive index of the lens is 1.5. [20]

iii. Calculate the refractive index of the water. [30]

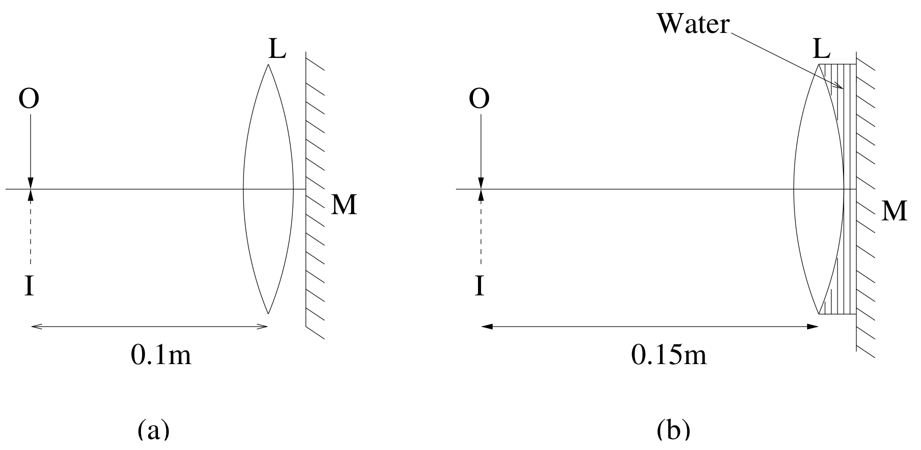

Figure 1:

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2. (a) Describe and explain the terms *plane polarised light* and *circularly polarised light*. [20]

(b) Describe how completely polarised light could be produced from unpolarised light using the following physical phenomena:

i. dichroism

ii. scattering [20]

(c) Maximum polarisation occurs when light is reflected from a clean glass surface at an angle of incidence 58 degrees. When a thin layer of an unknown liquid is applied to the glass surface, the angle of incidence for which maximum polarisation occurs at the surface of the glass is reduced to 50 degrees. Calculate the refractive indices of the glass and the liquid. [30]

(d) Determine with aid of sketches, the state of polarization of the wave described by:

i. $\vec{E}_{z,t} = E_0 \cos(\omega t - kz)\,\mathbf{i} - E_0 \sin(\omega t - kz)\,\mathbf{j}$ [15]

ii. $\vec{E}_{z,t} = E_0 \cos(\omega t - kz)\,\mathbf{i} - E_0 \sin\left(\frac{\pi}{2} - (\omega t - kz)\right)\,\mathbf{j}$ [15]

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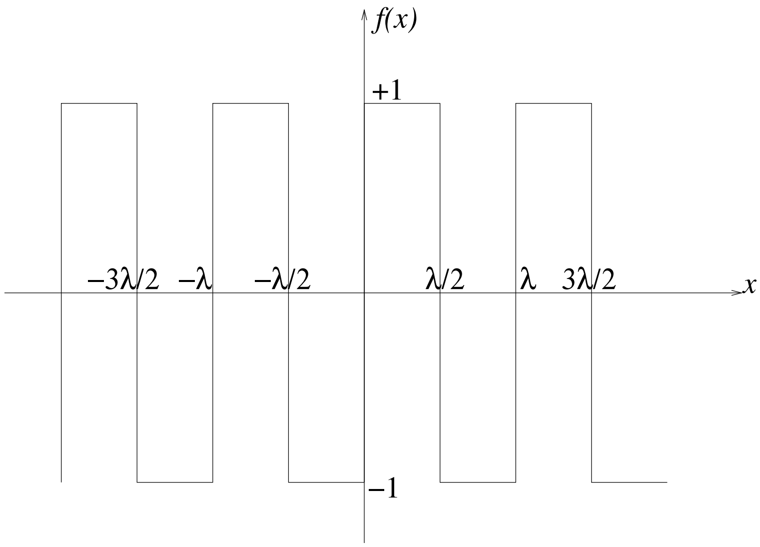
3. (a) Explain the terms *Fourier series* and *Fourier transform*.

(b) Determine the *Fourier series* of the square wave shown below and given by:

$$f(x) = +1 \qquad 0 \leq x < \frac{\lambda}{2}$$

$$f(x) = -1 \qquad \frac{\lambda}{2} \leq x < \lambda$$

and which is repeated to infinity.



[60]

(c) In part (b), if the wave is changed to a single pulse, explain what will happen to the Fourier series. [20]

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SECTION B: THERMODYNAMICS (Answer TWO questions)

4. (a) Explain briefly what is meant by

   i. an indicator diagram; [5]

   ii. a quasi-static process; [5]

   iii. a reversible process. [5]

   (b) A system consists of 1 kg-mole of helium, which has initial volume and temperature 1 m^3 and 300 K respectively. The gas is taken around the following reversible cycle:

   [A]: the volume is trebled isothermally;

   [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.

   Sketch the $P - V$ diagram for this cycle. [10]

   (c) What is the change of internal energy over the cycle? Explain your answer. [15]

   (d) 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]

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

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

(b) Writing the First Law of Thermodynamics in the form

$$\begin{aligned} dU &= đQ + dW \\ &= T\,dS - P\,dV \end{aligned}$$

in the usual notation, show that the change of internal energy for a Joule expansion is zero. [15]

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

(d) A system consisting of one kg-mole of an ideal gas undergoes a Joule expansion, from an initial volume 10^{-2} m^3 to a final volume 1 m^3.

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]

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

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

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

Define each of the symbols in this equation. [10]

(b) Show that, to a good approximation, the Clausius-Clapeyron equation for vapourization of a kg-mole of 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. [15]

(d) Under normal atmospheric pressure, water boils at 100° C. Calculate the value of P_0. [30]

(e) At the summit of Mauna Kea, Hawai'i, the atmospheric pressure is approximately 6.3×10^4 Pa. Calculate the temperature at which water boils at the summit of Mauna Kea. [25]

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