The Handbook of Mathematics, Physics and Astronomy Data is provided

KEELE UNIVERSITY

EXAMINATIONS, 2012/13

Level II

Friday 11^{th} January 2013, 13.00-15.00

PHYSICS/ASTROPHYSICS

PHY-20027

Optics & Thermodynamics

Candidates should attempt ALL of PART A, ONE question from PART B, and ONE question from PART C.

PART A yields 40% of the marks, PART B yields 30%, PART C yields 30%

NOT TO BE REMOVED FROM THE EXAMINATION HALL

PART A Answer all TEN questions

A1 A converging lens of focal length f is used to create a real image, twice the size of the object. How far is the object from the lens? [4]

A2 Explain the meaning of chromatic aberration in optical systems. [4]

A3 Is the wave described by:

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

linearly or circularly polarised? Justify your answer. [4]

A4 Show that the critical angle for total internal reflection is given by:

$$\theta_c = \sin^{-1}\left(\frac{n_t}{n_i}\right)$$

where n_t and n_i are the refractive indices of the refractive and incident media respectively. [4]

A5 Briefly describe the properties of a birefringent material and how it can be used to change the polarisation state of incident light. [4]

A6 The atmospheric pressure at the surface of the planet Mars is 0.6% of that at Earth's surface. Explain why water cannot exist in liquid form at the surface of Mars, and what the abundance of fluvial erosion patterns (i.e. formed by liquid flows) on Mars implies about the conditions on Mars in the past. [4]

A7 Explain why the efficiency of an engine must be less than 1, but the efficiency of a fridge exceeds 1. [4]

A8 Consider a well-insulated box, in which a piston can move. Gas on both sides of the piston is in thermal and pressure equilibrium. The piston is moved and then released. Explain whether the entropy of the Universe has increased, decreased, or remained the same. [4]

A9 Explain under what circumstances an adiabatic process involving an ideal gas is also isothermal. [4]

A10 Explain the usefulness in thermodynamics of the Gibbs function. [4]

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PART B Answer ONE out of TWO questions

B1 (a) The Michelson interferometer is a fundamental physical experiment with a wide range of applications.

i. Sketch and label a standard Michelson interferometer. Describe its operation to produce a circular interference pattern. [14]

ii. A Michelson interferometer is used to measure the refractive index of a gas. The gas is slowly allowed to flow into an evacuated cell of length L placed in one of the arms of the interferometer. A monochromatic light source of wavelength λ is used. If N fringes are displaced as the pressure changes from vacuum to atmospheric pressure, what is the refractive index of the gas as a function of N, L and λ? [8]

(b) A distant source emits coherent microwaves of wavelength 5 cm. The microwaves enter a long, narrow window in a building otherwise opaque to microwave radiation. If the window is 36 cm wide, what is the width of the central maximum of the diffraction pattern created on a wall 6.5 m from the window? [8]

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B2 (a) State Fermat's Principle and use it to derive the laws of reflection and refraction. [14]

(b) A slab of ice of thickness 50 cm is placed on a level floor over a speck of dust. Describe and find the location of the image of the speck as viewed from above. The index of refraction of ice is 1.309. [8]

(c) Maximum polarisation when light is reflected from a clean glass surface occurs for an angle of incidence of 58°. When a thin film of an unknown substance is applied to the glass surface, the angle of maximum polarisation at the glass surface is reduced to 50°. What are the refractive indices of the glass and unknown substance? [8]

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PART C Answer ONE out of TWO questions

C1 Consider an engine, "E", based on a cycle identical to a Carnot Cycle except the adiabates are replaced with isochores (i.e. constant volume processes). In what follows, we compare this engine with a Carnot engine operating between the same temperatures and the same extremes in volume.

(a) Show how the efficiencies of these two engines compare. [10]

(b) Sketch both cycles in a temperature–entropy diagram. [10]

(c) What is the entropy change over a cycle, for both engines, if they operate between temperatures of 300 and 350 K and volumes of 1 and 2 m^3, employing hundred moles of an ideal gas with internal energy $U = \frac{5}{2}RT$? [5]

(d) How – in a qualitative sense only – would your answers to parts (a)–(c) change if one of the processes in the cycle of engine "E" were irreversible? [5]

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C2 At low temperatures, the sublimation curve of water ice is

$$\log P_{\text{sub}} = \frac{T_{\text{sub}}}{10} - 20,$$

while the heat capacity (in J K^{-1} kg^{-1}) is

$$C = 7.5 \times T + 100.$$

(a) Use the Clausius–Clapeyron Equation to show that the molar latent heat of water ice at low temperatures is obtained from

$$L = 1.9 \times T^2.$$

(Hint: the identity $\log x = \ln x / \ln 10$ may be useful.) [10]

(b) Interplanetary space is characterised by $T_{\text{space}} = 100$ K, and has a density of 7 particles cm^{-3} near Earth. Show that in interplanetary space near Earth the sublimation temperature of water ice is $T_{\text{sub}} = 60$ K. [5]

(c) Consider a spherical comet of radius $R = 1$ km, made of water ice (density $\rho = 920$ kg $\text{m}^{-3} \equiv 51 \times 10^3$ mole m^{-3}), initially at $T = 30$ K. Assuming the comet stays at a similar distance from the Sun as Earth does, it absorbs 10^{17} J of energy per year.

i. Estimate the lifetime of the comet. [10]

ii. Explain – in a qualitative sense only – how the sublimation of the water ice will affect the value for T_{sub} and thus the answer to part (i). [5]