Queen Mary and Westfield College

UNIVERSITY OF LONDON

MSci EXAMINATION

ADVANCED TOPICS IN
GALACTIC ASTRONOMY
PHY-910

SUMMER 1998

Time allowed: TWO HOURS

Answer **TWO** questions only. No credit will be given for attempting a further question.

Each question carries 20 marks. The mark *provisionally allocated* to each section is indicated in the margin.

TURN OVER WHEN INSTRUCTED

Qu 1 a) With the aid of a diagram define the scattering angle, θ, scattering plane, and the azimuthal angle ϕ.
Given incident light along the z axis with electric field components E_{l0} & E_{r0} parallel and perpendicular to the scattering plane, the scattered electric field components E_l & E_r at distance R from the scatterer are given by

$$\begin{pmatrix} E_l \\ E_r \end{pmatrix} = \begin{pmatrix} S_2(\theta,\phi) & S_3(\theta,\phi) \\ S_4(\theta,\phi) & S_1(\theta,\phi) \end{pmatrix} \frac{e^{-ikR+ikz}}{ikR} \begin{pmatrix} E_{l0} \\ E_{r0} \end{pmatrix}$$

where $k = 2\pi/\lambda$ and λ is wavelength and where the matrix is known as the scattering amplitude matrix $S(\theta,\phi)$. For spherical scatterers why can the scattering amplitude matrix be simplified to

$$\begin{pmatrix} S_2(\theta) & 0 \\ 0 & S_1(\theta) \end{pmatrix}?$$

[3]

The Stokes parameter I is $I = E_l E_l^* + E_r E_r^*$ (where $*$ represents complex conjugate).
Starting from appropriate results give above, what further steps are needed to calculate the scattering cross section C_{sca}? [3]

b) For Rayleigh scattering by a material with isotropic polarisability α and with arbitrary shape the scattering amplitude matrix is

$$\begin{pmatrix} \cos\theta & 0 \\ 0 & 1 \end{pmatrix} ik^3\alpha.$$

Outline the assumptions and qualitative steps in the Rayleigh treatment of scattering by such a particle (no derivation of formulae is necessary), and explain why the two off diagonal matrix elements are zero. [4]

Show that for incident light with intensity components I_{l0} & I_{r0} the components of the scattered intensity for Rayleigh scattering are

$$I_l = \frac{k^4\alpha^2}{R^2} I_{l0}\cos^2\theta \qquad I_r = \frac{k^4\alpha^2}{R^2} I_{r0}.$$

For unpolarised incident light sketch the angular dependence of the total intensity of Rayleigh scattered radiation, and indicate the directions along which maximum and minimum polarisation of the scattered light will be observed. [3]

c) Define the extinction efficiency Q_{ext} for a scattering particle.
How is the optical extinction A_V related to this efficiency and the radii (a) and column densities (N_d) of spherical dust grains in the line of sight to a particular star?
What is the relation between extinction, scattering and absorption?
When considering the emission from dust grains why is Q_{abs} the absorption coefficient relevant? [4]

Define the asymmetry factor g and state, with qualitative justification how the radiation pressure efficiency Q_{pr} is related to other quantities above. [3]

Qu 2 a) Over the frequency range where emission from the grains is significant spherical dust grains of radius a may be assumed to have absorption efficiency $Q_{abs} = Q_0 a\nu^n$, where ν is frequency and Q_0 and n are constants. At frequencies where stars produce most of their radiation Q_{abs} can be taken to be $\simeq$ constant. Show that at radius R in an optically thin spherical circumstellar dust shell the equilibrium temperature T of such dust grains is

$$T = T_0(R/R_0)^{-p}$$

where R_0 is the radius at which $T = T_0$ and $p = 2/(4+n)$. What astrophysical factors, apart from n & R_0, does the value of T_0 depend on? [6]

b) Consider an optically thin shell of material within which the grain number density varies as $n = n_0(R/R_0)^{-q}$ between inner and outer radii (relative to R_0) R_{inner}/R_0 and R_{outer}/R_0, where n_0 is the number density of grains at radius R_0, and q is a constant. The grain temperature varies with R as $T = T_0(R/R_0)^{-p}$. For a temperature range from $T_{outer} = 0$ at R_{outer} to $T_{inner} = \infty$ at R_{inner} show that the flux density emitted from such a shell varies with frequency as a power law

$$S_\nu \propto \nu^\alpha \text{ where } \alpha = (2q-3) + \frac{n}{2}(q-1)$$

[8]

For the case where $n \simeq 2$ and $q \simeq 2$ sketch the spectrum, in the form $\log S_\nu$ versus $\log\nu$, expected for such a shell where the temperature goes instead from T_{inner} to T_{outer} (both of which are finite and non-zero). Indicate which features depend on the values of T at R_{inner} and R_{outer} and explain the qualitative reasons for the main features of this spectrum. [3]

Although dust emission around T Tauri stars follows a power law why is it clear, in this case, that this dust cannot be in a spherical shell? Where is it, and why (qualitatively) does it nevertheless also produce a power-law spectrum? [3]

Qu 3 a) Discuss the observational evidence constraining ideas of the composition, structure and shape of dust grains. [8]

Outline the theory of dust formation near stars, indicating the relation to observations. How can one explain the presence of organic ices on some grains? [4]

b) What evidence suggests the existence of protoplanetary disks around some young stellar objects? [3]

Why does a given mass of material produce much less observable emission when in the form of a planet rather than small dust grains? [1]

What processes may modify the size and radial distribution of grains in disks around stars?
How might one deduce, directly or indirectly from currently possible observations, the distribution of grains with distance from the central object? [4]