1. Answer and explain briefly but accurately:

   a) How would you distinguish the light of a thermal source from that of a laser, when the thermal source has been filtered to have a spectrum of the same width as the laser, and the laser intensity has been reduced to correspond to that of the thermal source? (*1.5 points*)

   b) The next generation of atomic clocks will use as clock frequency an electronic resonance transition in an atom or atomic ion. Why would one want to select the weakest transition that is accessible experimentally? (*1.5 points*)

   c) What is Rayleigh scattering? (*1.5 points*)

   d) What is meant by the longitudinal mode structure of a laser? How can a multi-mode laser be forced to operate in a single mode? (*1.5 points*)

2. a) How does the index of refraction of transparent materials behave as a function of the wavelength of light? Explain. (*1.5 points*)

   b) How does the index of refraction of a dielectric medium find an explanation through the process of light scattering? (*1.5 points*)

   c) A nonmagnetic medium has a dielectric constant that depends upon frequency ω and is given by $\varepsilon = \varepsilon_0(1 - A/\omega^2)$, where A is a positive constant and ε_0 is the permittivity of free space.

      (i) Write down the dispersion relation for an electromagnetic wave, which expresses ω as a function of wave number k. (*1 point*)

      (ii) Find the critical frequency below which a wave launched into the medium will not propagate through the medium, but rather will be evanescent or decaying. (*1 point*)

      (iii) Calculate the propagation distance over which the amplitude of the wave decays by a factor of e. (*1 point*)

3. A collimated light beam is incident normally on three very narrow, identical slits. At the center of the diffraction pattern projected on a faraway screen, the irradiance is I_{max}.

   a) Sketch the form of the diffraction pattern seen on the screen.

   b) If the irradiance I_P at some point P on the screen is zero, what is the phase difference between the waves arriving at point P from neighbouring slits?

   c) What is I_P/I_{max} at the points of secondary maxima of the diffraction pattern?

4. A circular lens in an earth satellite at 100 km height focuses images of objects on the ground onto a photographic film. The diameter of the lens is 0.5 m, its focal length 1 m, and the wavelength of the light recorded is 550 nm.

The image formed on the photographic film will be blurred. Two reasons for this are (neglecting atmospheric effects):

(1) the graininess of the photographic film, and
(2) diffraction by the lens aperture.

If the graininess of the film blurs the image of a point over a distance of 10 μm, which of the two sources of blurring will be more important? Give a quantitative reason for your answer.

5. (a) Write the rate equations for a two-level system, showing that a steady-state population inversion cannot be achieved by using direct optical pumping between the levels.

(b) Consider a three-level system that is pumped into level 3 in order to obtain an inversion between levels 2 and 1. Find the population inversion $\Delta N = N_2 - N_1$ as a function of the total number of atoms N, the pump rate Γ and the relaxation rates γ_{21}, γ_{31}, and γ_{32}. Show that if $\gamma_{32} \gg \gamma_{31}$, the inversion is achieved when $\Gamma > \gamma_{21}$.