CHE 420 INSTRUMENTAL ANALYSIS SPRING, 2005
MARIAN COLLEGE, INDIANAPOLIS

Class Test II **Name:**

Take-home, open-book. Show all work. Use additional paper as necessary.

1. Semiconductors and insulators as well as metals exhibit a work function ϕ. The work function of silicon is 1.14 eV (1eV = 1.602×10^{-19} J).
   (a) (i) If UV radiation of wavelength 300 nm impinges on a silicon surface, what is the maximum kinetic energy of the ejected photoelectrons? (ii) Repeat this calculation for a characteristic γ-ray from the decay of ^{241}Am, with wavelength 20.83 pm.
   (b) (i) and (ii) Calculate the velocities of these two electrons, given the electron rest mass $m_e = 9.10939 \times 10^{-31}$ kg and the relativistic kinetic energy equation

   $$E_k = (\gamma - 1)mc^2 \qquad \text{where} \qquad \gamma = \left(1 - \left(\frac{v}{c}\right)^2\right)^{-1/2}$$

   (c) Repeat the velocity calculation using the classical kinetic energy equation and comment on your results.

(cont. over)

2. (a) Calculate the energy density $\rho(\lambda,T)$ for a photon with λ=100 nm at a temperature of 1000 K for EM radiation at thermal equilibrium using (i) the Rayleigh-Jeans law and (ii) the Planck equation. Comment on your answers in the context of the "ultraviolet catastrophe". (Note: The energy in J per cubic meter contained within a given frequency range is given by $\rho(\lambda,T)d\lambda$.)
   (b) Calculate λ_{max} for (i) the radiation emitted by the Earth's surface (average temperature 18°C) and (ii) the plasma in a Tokamak-type nuclear fusion reactor (temperature approx. 10^7K). (iii) Identify the type of radiation involved in each case.

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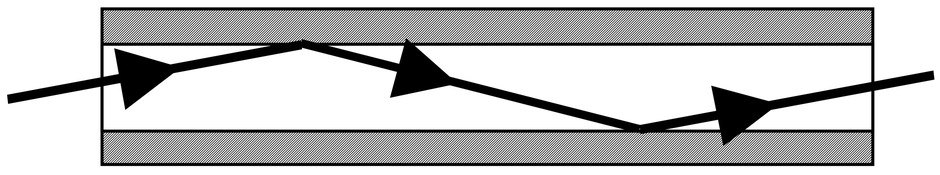
3. Optical fiber consists of a glass core surrounded by cladding having a different refractive index.



(a) The refractive index $\square_{core}$ of the core is 1.54, while that of the cladding $\square_{clad}$ is 1.52. Calculate the critical angle of the core/cladding interface.
(b) Light from a flame emission spectrum enters the optical fiber. The light includes the sodium D line, which has a wavelength of 589 nm in air. What is its wavelength in the fiber?
(c) Calculate the acceptance angle for this optical fiber.
(d) The optical fiber is then coupled directly to a dispersive optical element made from lanthanum flint glass with refractive index 1.80. How much light is lost by reflection at the interface?

(cont. over)

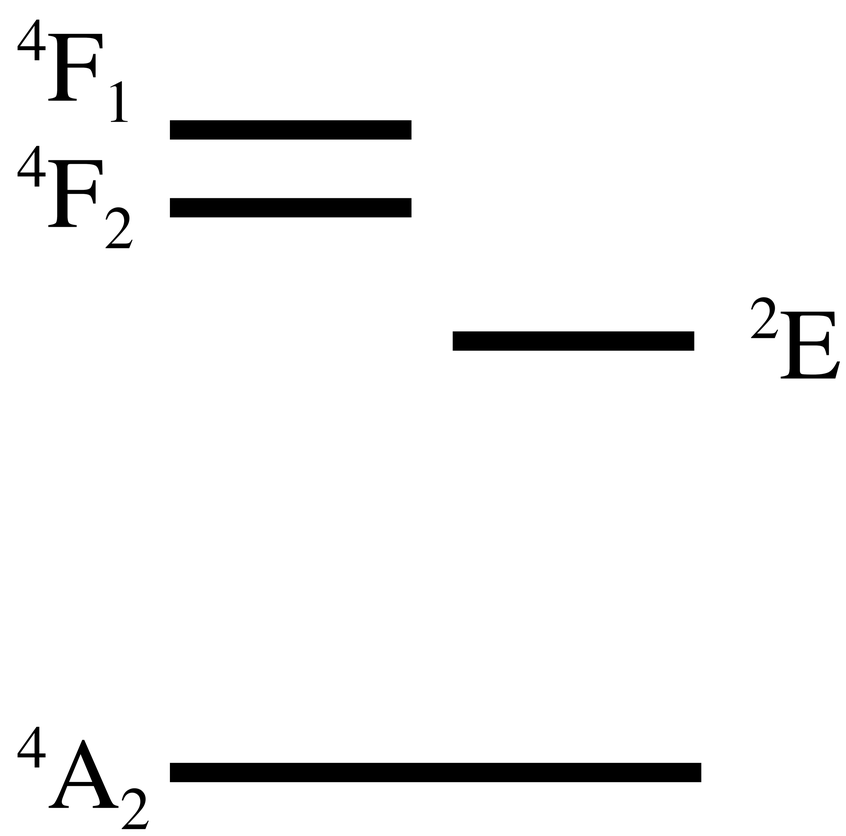
4. (a) Spectroscopic studies on the O_2 a $^1\Delta_g \leftarrow$ X $^3\Sigma_g^-$(0,0) transition (Newman et al., *J. Chem. Phys.* **110**(1999)10749*) yield an Einstein A coefficient of $2.19 \pm 0.07 \times 10^{-4}$ s^{-1}. (i) Given that the transition occurs at an energy equivalent to 7883.753(3) cm^{-1}, what is the value of the Einstein B coefficient? (ii) Given that the Einstein A coefficient is the reciprocal of the natural radiative lifetime of the excited state, what is the natural lifetime contribution to the total linewidth (in cm^{-1})? (iii) The measurements were carried out at 294 K and 380 Torr. What other factors affect linewidth under these conditions and how can their influence be minimized?

   (b) The overall spectrum obtained for the 0 ← 0 transition between v=0 vibrational sublevels of the two electronic states consists of many sharp lines. Give an account of the origin of this fine structure.

* This article can be found through Academic Search Premier using the keyword "Einstein coefficients."

(cont. over)

5. (a) If a crystalline sample of an organic molecule is irradiated with a pulse of laser light of wavelength 405 nm, and is observed to emit radiation with a wavelength of 440 nm and a decay lifetime of 10^{-3} s, is this fluorescence, or phosphorescence? Explain your reasoning.
(b) The figure below illustrates the Cr^{3+} electronic states involved in the ruby laser. (i) Clearly label this diagram showing the pumped transitions and the laser transition. (ii) Which transitions are *forbidden*, and why? (iii) Is this a three-level laser or a four-level laser? (Explain.)



END OF EXAM PAPER: 100 points total