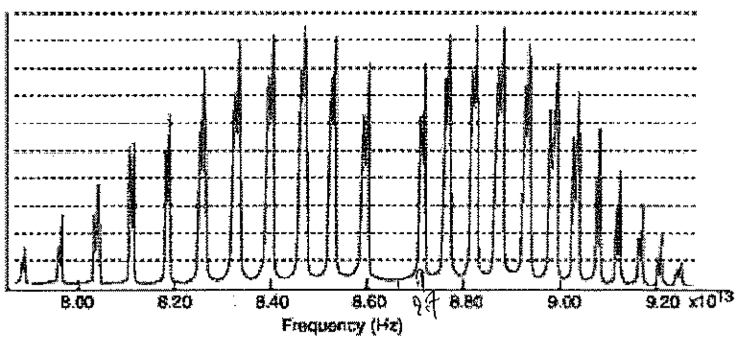
Physics 330 Example Exam 3
April 9, 2007
100 points total

1) Consider the vibrational-rotational absorption lines for the HCl molecule:



a) (5 pts) What type of bond is this?
b) (10 pts) What is the vibrational frequency?
c) (10 pts) What is the moment of inertia of the molecule?
d) (15 pts) For H: A=1, for Cl: A=17. Use the above spectrum to calculate the bond length

2) When deriving the Rutherford cross section, we equated two expressions of Δp to get an equation relating the impact parameter to the scattering angle.
a) (5 pts) What is the resulting equation?
b) (15 pts) Show the derivation of one of the Δp terms. (pick your favorite)

3) You have a selection of 1cm x 1cm x 1μm foils that you were planning to use for some very high energy scattering experiments. Someone opened the door to your lab at a bad time, and a breeze mixed up all your foils. You figure you can use Rutherford scattering to figure out what they are. The first one you try is a shiny-silver colored foil. It weighs 2.7×10^{-4} g. Determine what your sample is. Conveniently, you keep a source of ^{210}Po in your lab.

a) (10 pts) What is the kinetic energy of the alpha particles emitted from ^{210}Po?

b) (10 pts) You setup a collimated beam that gives 10^6 alphas per second, but in doing so, you accidentally put your hand in the beam for 1 s. What is the radiation dose equivalent of your exposure? Should you be worried about your health?

c) (20 pts) The foil scatters 2.36 alphas per second at an angle greater than $\pi/2$. What is the foil made from? State all your assumptions, and show your reasoning.

Example Exam 3

1.)

a.) ionic

b.) the missing absorbtion line is at the vibrational frequency,

$$f \cong 8.65 \times 10^{13}\ Hz$$

c.) For the first absorbtion line above vibration frequency, $E_\gamma = \hbar\omega + \frac{(l+1)\hbar^2}{I}$, $l=0$, $E_\gamma = 2\pi \cdot 8.7\times10^{13} \cdot \hbar$

$$I = \frac{\hbar^2}{E_\gamma - \hbar\omega} = \frac{\hbar^2}{2\pi\hbar\left(8.7\times10^{13}\,s^{-1} - 8.65\times10^{13}\,s^{-1}\right)}$$

$$= 2.1\times10^{-37}\ GeV\,s^2$$

d.) $I = \frac{M_1 M_2}{M_1+M_2} r^2$ $\quad M_1 = 1\,u$, $M_2 = 17\,u$ $\quad u = 0.935\ GeV/c^2$

$$r = \left[\frac{I(M_1+M_2)}{M_1 M_2}\right]^{1/2} = \left[\frac{2.1\times10^{-37}\ GeV\,s^2\,(3\times10^8\,m/s)^2}{0.935\ GeV}\cdot\frac{18}{17}\right]^{1/2}$$

$$= 0.15\ nm$$

2.)

a.) $$b = \frac{kq_1q_2}{mv^2}\sqrt{\frac{1+\cos\theta}{1-\cos\theta}}$$

b.) see rohlf p. ~~172~~ 173 - 174

3.)

a.) $E_K = \frac{Q(A-4)}{A}$ $\qquad {}^{210}Po \rightarrow {}^{206}Pb + \alpha$

$Q = m_{Po}c^2 - m_\alpha c^2 - m_{Pb}c^2$

$= 195.5564 \text{ GeV} - 3.7274 \text{ GeV} - 191.8236 \text{ GeV}$

$= 5.4 \text{ MeV}$

$E_K = 5.4 \text{ MeV} \left(\frac{210-4}{210} \right) = 5.3 \text{ MeV}$

b.)

Energy deposited in 1s

is $10^6 \times 5.3 \text{ MeV} \cdot \frac{1 \text{ J}}{6.24 \times 10^{12} \text{ MeV}} = 8.5 \times 10^{-7} \text{ J}$

Estimate hand is ~ 1kg

radiation absorbed dose is

$\frac{8.5 \times 10^{-7} \text{ J}}{1 \text{ Kg}} = 8.5 \times 10^{-7} \text{ Gy}$

radiation dose Equivalent is

$8.5 \times 10^{-7} \text{ J/Kg} \times 20 = 1.7 \times 10^{-5} \text{ Sv}$

↑ Q for α particles

3 c)

α Scattering for $\theta > \frac{\pi}{2}$ gives a cross section

$$\sigma = \pi Z^2 \left(\frac{Ke^2}{E_K}\right)^2$$

Scattering through a thin foil gives

$$\sigma = \frac{R_s A \,(10^{-3}\,\mathrm{Kg})}{R_i L N_A \rho}$$

Assume $A \sim 2Z$

$$\frac{2 R_s Z \,(10^{-3}\,\mathrm{kg})}{R_i L N_A \rho} = \pi Z^2 \left(\frac{Ke^2}{E_K}\right)^2$$

$$Z = \frac{2 R_s \,(10^{-3}\,\mathrm{kg})}{\pi R_i L N_A \rho \left(\frac{Ke^2}{E_K}\right)^2}$$

$$= \frac{2 \times (2.36\,\mathrm{s}^{-1})(10^{-3}\,\mathrm{Kg})}{\pi (10^6\,\mathrm{s}^{-1})(10^{-6}\,\mathrm{m})(6.02\times10^{23})\left(\frac{2.7\times10^{-7}\,\mathrm{Kg}}{(10^{-2}\,\mathrm{m})(10^{-2}\,\mathrm{m})(10^{-6}\,\mathrm{m})}\right)\left(\frac{1.44\times10^{-9}\,\mathrm{eV{\cdot}m}}{5.3\times10^{6}\,\mathrm{eV}}\right)}$$

$= 12.5$ either Al or Mg

Since A is typically greater than 2Z,

pick Al