University of Technology

Department of Laser & Opto-electronic Engineering

Final Examination 2011-2012

Subject:* Spectroscopy** | ***Class: *3^{rd} year*

Division: laser Engineering | ***Time:3 hours***

Examiner: Dr. Fareed Rashid | ***Date:*** *5 / 6 /2012*

Answer five questions only

Q1) Find:

- **(a)** The transition energy levels of a non rigid molecule (in wavenumber), if the rotational constant is 10 cm^{-1}, the centrifugal distortion constant is $2.31*10^{-3}$ cm^{-1} and the rotational quantum number is 2.
- **(b)** The vibration energy levels (in wavenumber) of anharmonic oscillator, if an oscillation frequency is 1876.2 cm^{-1}, the anharmonicity constant is 0.016 and the vibration quantum number is 3.

Q2) Starting from the combined rotation-vibration energy prove that:

$$\acute{\upsilon}_{spect} = \acute{w}_0 + 2Bm - 4Dm^3 \qquad cm^{-1} \qquad (m= + -1, + -2, \ldots.)$$

Q3)

- **(a)** Find the population levels according to Boltzmann distribution if the rotational quantum number is 2, the rotational constant is 5 cm^{-1}.
- **(b)** Find the angular momentum of the rotator.
- **(c)** Find the maximum population.

Q4) a) In the photo –electric effect experiment, if the stopping potential (v_0=4 volt) and the

8 work function of the surface is (φ=1.38 volts), find the wavelength of the emitted radiation.

4 **b)** State only 3 types of dispersers

Q5) a) Find the value of the energy difference between the n=2 and n=3 levels for lithium

8 atom (z=3) in electron volts(ev), then convert it into(cm^{-1}).

4 **b)** Explain stark effect.

Q6) a) Find the frequency of radiation (using Balmer series) of the fourth level (n=4) if the

8 Rydberg constant (R= 1.966 x10^7 m).

4 **b)** What are the two corrections of central field model of atoms having more than one electron.(state them only).

Useful constants

$k=1.381*10^{-23}$ JK^{-1}; $T=300$ ^0K (at room temperature); $h=6.626*10^{-34}$ Js;

$c = 2.998*10^8$ ms^{-1}; atomic masses: $H = 1.673*10^{-27}$ kg; $F= 31.55*10^{-27}$ kg.)

Charge of (e) $1.6*10^{-19}$ | *Mass of (e) $9.1*10^{-31}$ kg*

Q1.

(a) The transition energy levels for a non rigid molecule (in wavenumber).

$$\varepsilon_{J=2} = BJ(J+1) - DJ^2(J+)^2 \quad cm^{-1}$$

$$= 10 * 2(2+1) - [2.31 * 10^{-3} * (2)^2 (2+1)^2]$$

$$= 59.916 \quad cm^{-1}$$

(b) The vibrational energy levels of harmonic oscillator (in wavenumber).

$$\varepsilon_v = (v+\tfrac{1}{2})\bar{\omega}_e - (v+\tfrac{1}{2})^2 \bar{\omega}_e x_e \quad cm^{-1}$$

$$\therefore \varepsilon_{v=3} = (3+\tfrac{1}{2}) * 1876.2 - (3+\tfrac{1}{2})^2 * 1876.2 * 0.016$$

$$= 6198.9648 \quad cm^{-1}$$

Q.2 $\bar{\nu}_{spect.} = \bar{\omega}_o + 2Bm - 4Dm^3$ cm^{-1}, $(m = \mp 1, \mp 2, --)$

The combined rotation-vibration energy.

$E_{total} = E_{rot.} + E_{vib}$ joule

$\varepsilon_{total} = \varepsilon_{rot.} + \varepsilon_{vib.}$ cm^{-1}

$\varepsilon_{J,\nu} = \varepsilon_J + \varepsilon_\nu$

$\varepsilon_J = BJ(J+1) - DJ^2(J+1)^2 + HJ^3(J+1)^3 + \cdots$ cm^{-1}

$\varepsilon_\nu = (\nu + \frac{1}{2})\bar{\omega}_e - (\nu + \frac{1}{2})^2 \bar{\omega}_e x_e$ cm^{-1} $(\nu = 0, 1, 2, --)$

$\therefore \varepsilon_{J,\nu} = \varepsilon_J + \varepsilon_\nu$

$= BJ(J+1) - DJ^2(J+1)^2 + HJ^3(J+1)^3 + \cdots$
$+ (\nu + \frac{1}{2})\bar{\omega}_e - (\nu + \frac{1}{2})^2 \bar{\omega}_e x_e$ cm^{-1}

We ignore the small centrifugal distortion constant D, H, etc. then:

$\varepsilon_{Total} = \varepsilon_{J,\nu} = BJ(J+1) + (\nu + \frac{1}{2})\bar{\omega}_e - x_e(\nu + \frac{1}{2})^2 \bar{\omega}_e$

We have $\Delta\nu = \mp 1, \mp 2, ----$
$\Delta J = \mp 1$

then the transition: (for $\nu = 0 \rightarrow \nu = 1$)

$\Delta\varepsilon_{J,\nu} = \varepsilon_{J',\nu=1} - \varepsilon_{J'',\nu=0}$

$= BJ'(J'+1) + 1\frac{1}{2}\bar{\omega}_e - 2\frac{1}{4}\bar{\omega}_e x_e - \{BJ''(J''+1) + \frac{1}{2}\bar{\omega}_e - \frac{1}{4}x_e \bar{\omega}_e\}$

$= \bar{\omega}_o + B(J' - J'')(J' + J'' + 1)$ cm^{-1}

and $\bar{\omega}_o = \bar{\omega}_e(1 - 2x_e)$

for $\Delta J = +1$, i.e $J' = J''+1$ or $J' - J'' = +1$

$$\therefore \Delta \mathcal{E}_{J,v} = \bar{\omega}_0 + 2B(J''+1) \quad cm^{-1} \quad (1) \quad (J''=0,1,2,\cdots)$$

for $\Delta J = -1$, i.e $J'' = J'+1$ or $J' - J'' = -1$

$$\therefore \Delta \mathcal{E}_{J,v} = \bar{\omega}_0 - 2B(J'+1) \quad cm^{-1} \quad (2) \quad (J' \neq 0,1,2,\cdots)$$

$$\therefore \Delta \mathcal{E}_{J,v} = \bar{\nu}_{spect.} = \bar{\omega}_0 + 2Bm \quad cm^{-1} \quad , (m = \mp 1, \mp 2, \cdots)$$

replacing m by $J''+1$ in eq. (1) and $J'+1$ in eq. (2)

The inclusion of centrifugal distortion constant D leads to the following expression of the spectrum

$$\Delta \mathcal{E} = \bar{\nu}_{spect.} = \bar{\omega}_0 + 2Bm - 4Dm^3 \quad cm^{-1}$$

$$(m = \mp 1, \mp 2, \cdots)$$

Q3. (a) population levels

$$\frac{N_1}{N_0} = \exp\left\{-Bhc\,J(J+1)/KT\right\}$$

$$= \exp\left\{-\frac{5 * 6.626 * 10^{-34} * 2.998 * 10^{8} * 2(2+1)}{300 * 1.38 * 10^{-23}}\right\}$$

$$= \exp(-1.4394 * 10^{-3})$$

$$= 0.99856$$

(b) Angular momentum

$$P = \sqrt{J(J+1)} \quad \text{units}$$

$$= \sqrt{2(2+1)}$$

$$= \sqrt{6}$$

(c) Maximum Population

$$J = \sqrt{\frac{KT}{2hcB}} - \frac{1}{2}$$

$$= \sqrt{\frac{1.38 * 10^{-23} * 300}{2 * 6.626 * 10^{-34} * 2.998 * 10^{8} * 5}} - \frac{1}{2}$$

$$= 4.5151877 21 - \frac{1}{2}$$

$$= 4.0651$$

Q.4

a/ $eV_0 = hf - \varphi$

$\varphi = 1.38\ ev$

$e = 1.6 \times 10^{-19}\ C$

$V_0 = 4$ volt

$f = ?$

0.5

$\therefore\ 1.6 \times 10^{-19} \times 4 = 6.63 \times 10^{-34} \times f - 1.38 \times 1.6 \times 10^{-19}$

$\therefore\ f = \dfrac{6.4 \times 10^{-19} + 1.38 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}}$

$f = \cancel{0.97} \times 10^{15}$ hertz or s^{-1}

1.29

0.6.8

$f = \dfrac{c}{\lambda} \Rightarrow \lambda = \dfrac{c}{f}$

$= \dfrac{3 \times 10^{8}}{\cancel{0.97} \times 10^{15}}$ 1.29

$= \cancel{3.96} \times 10^{-7}$ m

$= \cancel{396}$ nm

2.309 m

= 230.9 nm

b/ 1. Prism

2. Diff. grating

3- interferometer

Q.5

a/ $E_n = \dfrac{-13.6\ Z^2}{n^2}$

for Li $\Rightarrow Z = 3$

$E_2 = \dfrac{-13.6 \times 9}{4} = -30.6$ ev

$E_3 = \dfrac{-13.6 \times 9}{9} = -13.6$ ev

$\Delta E = 17$ ev

5

$17 eV \times 1.6 \times 10^{-19} = 27.2 \times 10^{-19}$ joule

b/ stark effect

is the splitting of energy levels due to the application of electric field

The Applied E-field distort electron configuration So induce a dipole moment αE where α is the polarizability

hence the interaction of the induced moment with the Electric field yields αE^2

Q.6

a/
$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$
$$\frac{f}{c} = 1.966 \times 10^7 \left(\frac{1}{4} - \frac{1}{16}\right)$$
$$f = 1.966 \times 10^7 \left(\frac{3}{16}\right) \times 3 \times 10^8$$
$$f = 1.1 \times 10^{15}\ s^{-1}$$

b/
1. Electrostatic interaction (L & S coupling)

2. Magnetic interaction (J q.no.)