

Session #3: Homework Solutions

Problem #1

From a standard radio dial, determine the maximum and minimum wavelengths

($\lambda_{\max}$ and $\lambda_{\min}$) for broadcasts on the

- (a) AM band
- (b) FM band

Solution

$$c = v\lambda, \therefore \lambda_{\min} = \frac{c}{v_{\max}}; \lambda_{\max} = \frac{c}{v_{\min}}$$

$$\text{AM} \quad \lambda_{\min} = \frac{3 \times 10^8 \text{ m/s}}{1600 \times 10^3 \text{ Hz}} = 188 \text{ m}$$

$$\lambda_{\max} = \frac{3 \times 10^8}{530 \times 10^3} = 566 \text{ m}$$

$$\text{FM} \quad \lambda_{\min} = \frac{3 \times 10^8}{108 \times 10^6} = 2.78 \text{ m}$$

$$\lambda_{\max} = \frac{3 \times 10^8}{88 \times 10^6} = 3.41 \text{ m}$$

Problem #2

For light with a wavelength (λ) of 408 nm determine:

- (a) the frequency
- (b) the wave number
- (c) the wavelength in Å
- (d) the total energy (in Joules) associated with 1 mole of photons
- (e) the "color"

Solution

To solve this problem we must know the following relationships:

$$v\lambda = c; 1/\lambda = \bar{\nu}; 1 \text{ nm} = 10^9 \text{ m} = 10 \text{ Å}$$

$$E = hv; E_{\text{molar}} = hv \times N_A \quad (N_A = 6.02 \times 10^{23})$$

$$(a) \quad v \text{ (frequency)} = \frac{c}{\lambda} = \frac{3 \times 10^8 \text{ m/s}}{408 \times 10^{-9} \text{ m}} = 7.353 \times 10^{14} \text{ s}^{-1}$$

$$(b) \quad \bar{\nu} \text{ (wavenumber)} = \frac{1}{\lambda} = \frac{1}{408 \times 10^{-9} \text{ m}} = 2.45 \times 10^6 \text{ m}^{-1}$$

$$(c) \quad \lambda = 408 \times 10^{-9} \text{ m} \times \frac{10^{10} \text{ \AA}}{\text{m}} = 4080 \text{ \AA}$$

$$(d) \quad E = h\nu \times N_A = 6.63 \times 10^{-34} \times 7.353 \times 10^{14} \times 6.02 \times 10^{23} \text{ J/mole}$$

$$= 2.93 \times 10^5 \text{ J/mole} = 293 \text{ kJ/mole}$$

(e) visible spectrum: violet (400 nm) red (700 nm) 408 nm = UV

Problem #3

For “yellow radiation” (frequency, ν , = $5.09 \times 10^{14} \text{ s}^{-1}$) emitted by activated sodium, determine:

- (a) the wavelength (λ) in [m]
- (b) the wave number ($\bar{\nu}$) in [cm^{-1}]
- (c) the total energy (in kJ) associated with 1 mole of photons

Solution

(a) The equation relating ν and λ is $c = \nu\lambda$ where c is the speed of light = $3.00 \times 10^8 \text{ m/s}$.

$$\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^8 \text{ m/s}}{5.09 \times 10^{14} \text{ s}^{-1}} = 5.89 \times 10^{-7} \text{ m}$$

(b) The wave number is $1/\text{wavelength}$, but since the wavelength is in m, and the wave number should be in cm^{-1} , we first change the wavelength into cm:

$$\lambda = 5.89 \times 10^{-7} \text{ m} \times 100 \text{ cm/m} = 5.89 \times 10^{-5} \text{ cm}$$

Now we take the reciprocal of the wavelength to obtain the wave number:

$$\bar{\nu} = \frac{1}{\lambda} = \frac{1}{5.89 \times 10^{-5} \text{ cm}} = 1.70 \times 10^4 \text{ cm}^{-1}$$

(c) The Einstein equation, $E = h\nu$, will give the energy associated with one photon since we know h , Planck's constant, and ν . We need to multiply the energy obtained by Avogadro's number to get the energy per mole of photons.

$$h = 6.62 \times 10^{-34} \text{ J.s}$$

$$\nu = 5.09 \times 10^{14} \text{ s}^{-1}$$

$$E = h\nu = (6.62 \times 10^{-34} \text{ J.s}) \times (5.09 \times 10^{14} \text{ s}^{-1}) = 3.37 \times 10^{-19} \text{ J per photon}$$

This is the energy in one photon. Multiplying by Avogadro's number:

$$E \cdot N_{Av} = (3.37 \times 10^{-19} \text{ J per photon}) \left(\frac{6.023 \times 10^{23} \text{ photons}}{\text{mole}} \right)$$

$$= 2.03 \times 10^5 \text{ J per mole of photons}$$

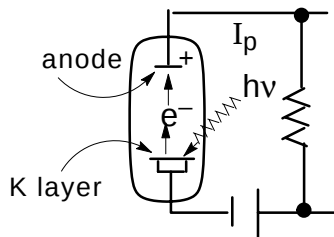
we get the energy per mole of photons. For the final step, the energy is converted into kJ:

$$2.03 \times 10^5 \text{ J} \times \frac{1 \text{ kJ}}{1000 \text{ J}} = 2.03 \times 10^2 \text{ kJ}$$

Problem #4

Potassium metal can be used as the active surface in a photodiode because electrons are relatively easily removed from a potassium surface. The energy needed is $2.15 \times 10^5 \text{ J}$ per mole of electrons removed ($1 \text{ mole} = 6.02 \times 10^{23}$ electrons). What is the longest wavelength light (in nm) with quanta of sufficient energy to eject electrons from a potassium photodiode surface?

Solution



I_p , the photocurrent, is proportional to the intensity of incident radiation, i.e. the number of incident photons capable of generating a photoelectron.

This device should be called a phototube rather than a photodiode – a solar cell is a photodiode.

$$\text{Required: } 1\text{eV} = 1.6 \times 10^{-19} \text{ J}$$

$$E_{\text{rad}} = h\nu = (hc)/\lambda$$

The question is: below what threshold energy ($h\nu$) will a photon no longer be able to generate a photoelectron?

$$2.15 \times 10^5 \text{ J/mole photoelectrons} \times \frac{1 \text{ mole}}{6.02 \times 10^{23} \text{ photoelectrons}}$$

$$= 3.57 \times 10^{-19} \text{ J/photoelectron}$$

$$\lambda_{\text{threshold}} = \frac{hc}{3.57 \times 10^{-19}} = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{3.57 \times 10^{-19}} = 5.6 \times 10^{-7} \text{ m} = 560 \text{ nm}$$

Problem #5

For red light of wavelength (λ) 6.7102×10^{-5} cm, emitted by excited lithium atoms, calculate:

- (a) the frequency (ν) in s^{-1} ;
- (b) the wave number ($\bar{\nu}$) in cm^{-1} ;
- (c) the wavelength (λ) in nm;
- (d) the total energy (in Joules) associated with 1 mole photons of the indicated wavelength.

Solution

(a) $c = \lambda\nu$ and $\nu = c/\lambda$ where ν is the frequency of radiation (number of waves/s).

$$\text{For: } \lambda = 6.7102 \times 10^{-5} \text{ cm} = 6.7102 \times 10^{-7} \text{ m}$$

$$\nu = \frac{2.9979 \times 10^8 \text{ ms}^{-1}}{6.7102 \times 10^{-7} \text{ m}} = 4.4677 \times 10^{14} \text{ s}^{-1} = 4.4677 \text{ Hz}$$

$$(b) \quad \bar{\nu} = \frac{1}{\lambda} = \frac{1}{6.7102 \times 10^{-7} \text{ m}} = 1.4903 \times 10^6 \text{ m}^{-1} = 1.4903 \times 10^4 \text{ cm}^{-1}$$

$$(c) \quad \lambda = 6.7102 \times 10^{-5} \text{ cm} \times \frac{1 \text{ nm}}{10^{-7} \text{ cm}} = 671.02 \text{ nm}$$

$$(d) \quad E = \frac{hc}{\lambda} = \frac{6.62 \times 10^{-34} \text{ Js} \times 2.9979 \times 10^8 \text{ ms}^{-1}}{6.7102 \times 10^{-7} \text{ m}}$$
$$= 2.96 \times 10^{-19} \text{ J/photon} = 1.78 \times 10^5 \text{ J/mole photons}$$

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