Photovoltaic Effect:

1. a) K.E. max for emitted electrons
   
   \[ K.E. = \text{Stopping Voltage} \]
   
   The Photon Energy \((h\nu)\) is given to the electron, but some of this energy is required just to pull the electron off of the surface of the metal. The work function \((\Phi)\) is the amount of energy required to pull an electron free of the surface.
   
   \[ h\nu = \Phi + K.E. \text{electron} \]
   
   \[ y = mx + b \]
   
   The slope of the line is \(h\nu\)
   
   \[ \text{Intercept} = -\Phi \]

   The cutoff frequency \(\nu_0\) (Point A) is when the light has just enough energy to free the electron from the surface. \(h\nu_0 = \Phi\). Below \(\nu_0\), there is not enough energy to free an electron. Above \(\nu_0\), there is energy left over.

2. Consider a beam of \(N\) Photons. Each Photon has \(E_{photon} = h\nu\)

   \[ \text{Intensity} = \frac{\text{Power}}{\text{Area}} = \frac{\text{Energy}}{\text{Time} \cdot \text{Area}} \]

   \[ \text{Total} = N_{\text{photons}} \cdot h\nu \]

   \[ \text{Intensity} = \frac{N_{\text{photons}}}{\text{time} \cdot \text{Area}} \]

   \[ N_{\text{photons}} \cdot \frac{\text{time}}{\text{Area}} = \frac{\text{Intensity} \cdot \text{Area}}{h\nu} \]

   For a constant intensity, \(N_{\text{photons}} \cdot \frac{\text{time}}{\text{Area}} \alpha \frac{1}{\nu} \)

   Each photoelectron is caused (Excited) by a single photon.

   More photons leads to more electrons = More Current.

   \[ \text{Current} \alpha N \alpha \frac{1}{\nu} \]

   However, below \(\nu_0\), there are more photons but the photons don't have enough energy to free electrons (see Page 290).
2) **Photo Electric Effect:**
Each photo electron receives energy from a single photon. More photons will not change the energy of individual electrons. However, more photons will create more photo electrons and therefore more photocurrent. Assume $V > V_A$.

3)

$$\lambda = 580 \text{ nm} \quad c = \frac{\lambda \nu}{V}$$

$$V = \frac{c}{\lambda} = \frac{3 \times 10^8 \text{ m/s}}{580 \times 10^{-9} \text{ m}} = 5.2 \times 10^{14} \text{ Hz}$$

$$E_{\text{photo}} = h \nu = 4.1 \times 10^{-15} \text{ eV} \cdot 5.2 \times 10^{14} \frac{1}{2} = 2.1 \text{ eV}$$

$$E_{\text{total}} = N_{\text{photons}} \cdot E_{\text{photo}} = 100 \cdot 2.1 \text{ eV} = 210 \text{ eV}$$

4) **Visible region**

$$\lambda = 400 \text{ nm} - 700 \text{ nm}$$

$$\lambda \approx 550 \text{ nm} \quad \text{(Green)}$$

Wien's Displacement Law

$$\lambda T_{\text{max}} = 2.9 \times 10^{-3} \text{ mK}$$

$$T_{\text{max}} = 2.9 \times 10^{-3} \text{ mK} / 550 \times 10^{-9} \text{ m} = 5300 \text{ K}$$

$$T \approx 4000 - 7000 \text{ Kelvin} \quad (7000 \text{ nm})$$

$$ \text{(4000 nm)}$$

5) **Area of the human body**

$$A \approx 2 \text{ m}^2 \times 2 \text{ sides}$$

$$E_{\text{missivity}} = 1 \quad \text{(Painted Black)}$$

Temperature $98.6^\circ F = 37^\circ C$

$$= (37 + 273) \text{ K} = 310 \text{ K}$$

$$P_{\text{power}} = eA \alpha T^4 = 1.2 \text{ m}^2 \cdot 5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \cdot \text{K}^4} \times (310 \text{ K})^4$$

$$= 1050 \text{ W}$$

See Notes on Next Page
5) Note! How much does a person heat a room?
   - Consider only Radiation: 
     \[ P_{\text{net}} = P_{\text{out}} - P_{\text{in}} \]
     \[ = 1.05 \times 10^2 \text{ W} - 1,220 \times 5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4 \]
     \[ = 1.05 \times 10^2 \text{ W} - 8.40 \text{ W} = 2.00 \text{ W} \]
   - Consider Total Power from Food intake
     \[ 2500 \text{ Cal} = 2500 \times 10^3 \text{ calories} \]
     \[ 1 \text{ cal} = 4.2 \text{ J} \]
     \[ P_{\text{food}} = \frac{E}{\text{Time}} = \frac{1.05 \times 10^2 \text{ J}}{1 \text{ day}} = 120 \text{ W} \]

   Why the difference? \( E \ll 1 \text{ and Clothes!} \)

6) Cat Temp \( \sim 101^\circ \text{F} \approx 38^\circ \text{C} \approx 311 \text{ K} \)
   \( k = \frac{2.9 \times 10^{-2} \text{ m/s}}{311 \text{ K}} \approx 9.3 \times 10^{-6} \text{ m} \)

   Blood Body \( T \approx 100^\circ \text{C} \approx 373 \text{ K} \) (White with Fury \( \approx 6000 \text{ K} \)

7) How much Power off Each Surface?
   \[ P = \varepsilon A \sigma T^4 \]
   \( \varepsilon = 1 \) (Black), \( A = 0.1 \text{ m} \times 0.1 \text{ m} = 0.01 \text{ m}^2 \)
   \( P_{\text{hot}} = 1.0 \times 0.01 \times 5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4 \)
   \[ = 4.6 \text{ W} \]
   \( P_{\text{cold}} = 1.0 \times 0.01 \times 5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4 \)
   \( = 0.9 \text{ W} \)

   Hot Plate gives off 4.6 W and absorbs 0.9 W
   \( \text{Net loss} = 3.7 \text{ W} \)

   Cold Plate gives off 0.9 W and absorbs 4.6 W
   \( \text{Net gain} = 3.7 \text{ W} \)

If cooler plate is at 0 K
the answer doesn't change very much
Heat Transfer = 4.6 W
8) Consider one dimensional standing waves.

\[ \lambda = \frac{2L}{n} \]
\[ v = \frac{\text{Vol}}{\lambda} = \frac{\text{Vol}}{2L} \quad n = \nu_0 n \]
\[ v = \frac{\text{Vol}}{2L} = \frac{5000 \text{m/s}}{2 \times 0.1 \text{m}} = 25 \text{kHz} \]

The crystal is square so \( \nu_x = \nu_y = 25 \text{kHz} \)

**How Many Modes?**

These denote the possible modes.

\[ v = \sqrt{v_x^2 + v_y^2} \]

\[ N_{\text{modes}} = \frac{\text{Shaded Area}}{\text{Area per mode}} = \frac{\text{Shaded Area}}{\nu_x \nu_y} \]

Area \( \approx \) Length \( AD \times \text{Length } AB \)
\[ = \frac{1}{4} 2\pi L \times 2\pi L \]

Quadrant circumference

\[ N = \frac{1}{4} 2\pi L \text{ d}V / \nu_0^2 \]
\[ = \frac{\pi}{2} \text{ MHz}^2 \times 0.1 \text{ MHz} / (6.025 \text{ MHz})^2 = \sqrt{2.51} \]

Note: you could also use \( 1.1 \text{ MHz} = \nu \) with little change in the result.
9) a) Compton Formula
\[ \Delta \lambda = \frac{h}{m c} (1 - \cos \theta) \]
\[ \Delta \omega = \frac{\Delta \lambda}{\lambda} = \frac{\frac{\hbar}{\lambda m c}}{\frac{2\hbar}{m c^2}} = \frac{\frac{\hbar}{\lambda m c}}{\frac{\hbar c}{m c^2}} \]

For \( m \to \infty \), \( \Delta \omega \to 0 \) and \( \omega \to 0 \)
For small mass, the scattered photon's lower energy
For large mass, the scattered photon has the same energy as the initial photon.

If photons can scatter off of electrons (light) and atoms (heavy) then the scattered beam will have 2 components with different energies.

b) Ping pong ball will lose some energy if it bounces off a (light) golf ball.

Ping pong ball will lose very little energy if it bounces off a bowling ball.

c) Compton scattering treats the photon like a particle bouncing (low energy) light off of a particle. Transfers some energy to the particle. The amount of transfer depends on the mass of the target particle.

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0) See Attached.

K.E. = Stopping Voltage = h \nu - Q

Even for \( h = 4.2 \times 10^{-15} \text{ eV} \), \( Q = 2.1 \text{ eV} \)

\[ K.E. = 4.2 \times 10^{-15} \text{ eV} - 2.1 \text{ eV} \]

I) a) 400-700 nm are 15% of spectrum. So 85% of the power is wasted!
b) 400nm = The 700nm Red 1500nm
\[ \frac{T}{I} = 0.2 \times 12 \quad \frac{2.9 \times 12}{1.0} \quad \frac{3.15 \times 12}{1.0} \]

7% at 400nm 76% at 700nm 100% at 1000nm

Incandescent lights highlight reds not blues.
HW5, Question 10

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LINEST

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uncert. 6.62125E-17 0.050753

HW5, Question 11

(see p95, eq. 3.25)

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Sum (400-700) 5.12416E+12
sum (400-2500) 3.83416E+13
Visible Fraction 0.133644966