Physics 123 - 2013 - Solutions to Prob. Set 9

1.
37-4

We use Eq. 37-1 with a temperature of $98°F = 37°C = 310 K$.

$$\lambda_P = \frac{(2.90 \times 10^{-3} m \cdot K)}{T} = \frac{(2.90 \times 10^{-3} m \cdot K)}{(310 K)} = 9.4 \times 10^{-6} m = \boxed{9.4 \mu m}$$

2.
37-6

We use Eq. 37-3.

$$E = hf = (6.626 \times 10^{-34} J \cdot s)(104.1 \times 10^{6} Hz) = \boxed{6.898 \times 10^{-26} J}$$

3.
37-8

We use Eq. 37-3 with the fact that $f = c/\lambda$ for light.

$$\lambda = \frac{c}{f} = \frac{hc}{E} = \frac{(6.63\times10^{-34}\,\text{J}\cdot\text{s})(3.00\times10^{8}\,\text{m/s})}{(1.60\times10^{-19}\,\text{J/eV})(380\times10^{3}\,\text{eV})} = 3.27\times10^{-12}\,\text{m} \approx \boxed{3.3\times10^{-3}\,\text{nm}}$$

Significant diffraction occurs when the opening is on the order of the wavelength. Thus there would be $\boxed{\text{insignificant diffraction}}$ through the doorway.

4.
37-9

We use Eq. 37-3 with the fact that $f = c/\lambda$ for light.

$$E_{\text{min}} = hf_{\text{min}} \rightarrow f_{\text{min}} = \frac{E_{\text{min}}}{h} = \frac{(0.1\text{eV})(1.60\times10^{-19}\,\text{J/eV})}{(6.63\times10^{-34}\,\text{J}\cdot\text{s})} = 2.41\times10^{13}\,\text{Hz} \approx \boxed{2\times10^{13}\,\text{Hz}}$$

$$\lambda_{\text{max}} = \frac{c}{f_{\text{min}}} = \frac{(3.00\times10^{8}\,\text{m/s})}{(2.41\times10^{13}\,\text{Hz})} = 1.24\times10^{-5}\,\text{m} \approx \boxed{1\times10^{-5}\,\text{m}}$$

5.
37-12

The longest wavelength corresponds to the minimum frequency. That occurs when the kinetic energy of the ejected electrons is 0. Use Eq. 37-4a.

$$K = hf_{min} - W_0 = 0 \rightarrow f_{min} = \frac{c}{\lambda_{max}} = \frac{W_0}{h} \rightarrow$$

$$\lambda_{max} = \frac{ch}{W_0} = \frac{(3.00\times10^8\,\text{m/s})(6.63\times10^{-34}\,\text{J}\cdot\text{s})}{(3.70\,\text{eV})(1.60\times10^{-19}\,\text{J/eV})} = \boxed{3.36\times10^{-7}\,\text{m}} = 336\,\text{nm}$$

6.
37-14

We divide the minimum energy by the photon energy at 550 nm to find the number of photons.

$$E = nhf = E_{min} \rightarrow n = \frac{E_{min}}{hf} = \frac{E_{min}\lambda}{hc} = \frac{(10^{-18}\,\text{J})(550\times10^{-9}\,\text{m})}{(6.63\times10^{-34}\,\text{J}\cdot\text{s})(3.00\times10^8\,\text{m/s})} = 2.77 \approx \boxed{3\text{ photons}}$$

7.
37-15

The photon of visible light with the maximum energy has the least wavelength. We use 410 nm as the lowest wavelength of visible light.

$$hf_{max} = \frac{hc}{\lambda_{min}} = \frac{(6.63\times10^{-34}\,\text{J}\cdot\text{s})(3.00\times10^{8}\,\text{m/s})}{(1.60\times10^{-19}\,\text{J/eV})(410\times10^{-9}\,\text{m})} = 3.03\text{eV}$$

Electrons will not be emitted if this energy is less than the work function.
The metals with work functions greater than 3.03 eV are $\boxed{\text{copper and iron}}$

8.
37-17

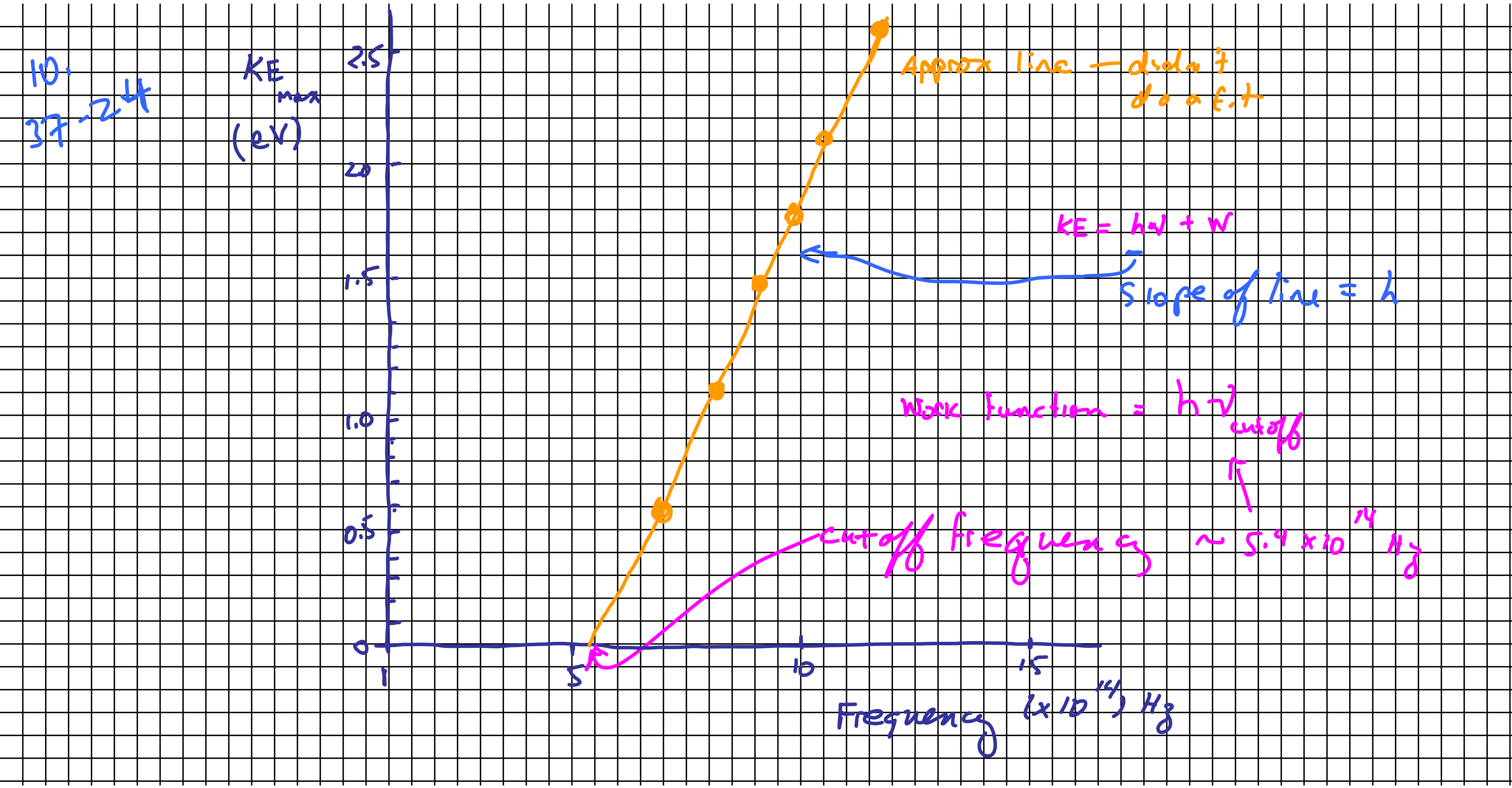
The photon of visible light with the maximum energy has the minimum wavelength. We use Eq. 37-4b to calculate the maximum kinetic energy.

$$K_{max} = hf - W_0 = \frac{hc}{\lambda} - W_0 = \frac{1240\text{ eV}\cdot\text{nm}}{410\text{ nm}} - 2.48\text{ eV} = \boxed{0.54\text{ eV}}$$

9.
37-19

We use Eq. 37-4b to calculate the work function.

$$W_0 = hf - K_{max} = \frac{hc}{\lambda} - K_{max} = \frac{1240\text{ eV}\cdot\text{nm}}{285\text{ nm}} - 1.70\text{ eV} = \boxed{2.65\text{ eV}}$$



10.
37-24
KE max (eV)
2.5
2.0
1.5
1.0
0.5
0
1
5
10
15
Frequency (x10^14) Hz
Approx line — didn't do a fit
KE = hν + W
Slope of line = h
Work function = hν cutoff
cutoff frequency ~ 5.4 x10^14 Hz

11.
37-28

We use Eq. 37-6b. Note that the answer is correct to two significant figures.

$$\Delta\lambda = \frac{h}{m_e c}(1-\cos\phi) \rightarrow$$

$$\phi = \cos^{-1}\left(1-\frac{m_e c\Delta\lambda}{h}\right) = \cos^{-1}\left(1-\frac{(9.11\times10^{-31}\,\text{kg})(3.00\times10^{8}\,\text{m/s})(1.5\times10^{-13}\,\text{m})}{(6.63\times10^{-34}\,\text{J}\cdot\text{s})}\right) = \boxed{20^\circ}$$

12.
37-32

We find the change in wavelength for each scattering event using Eq. 37-6b, with a scattering angle of $\phi = 0.50^\circ$. To calculate the total change in wavelength, we subtract the initial wavelength, obtained from the initial energy, from the final wavelength. We divide the change in wavelength by the wavelength change from each event to determine the number of scattering events.

$$\Delta\lambda = \frac{h}{m_e c}(1-\cos 0.5^\circ) = \frac{(6.63\times10^{-34}\,\text{J}\cdot\text{s})(1-\cos 0.5^\circ)}{(9.11\times10^{-31}\,\text{kg})(3.00\times10^{8}\,\text{m/s})} = 9.24\times10^{-17}\,\text{m} = 9.24\times10^{-8}\,\text{nm}$$

$$\lambda_0 = \frac{hc}{E_0} = \frac{(6.63\times10^{-34}\,\text{J}\cdot\text{s})(3.00\times10^{8}\,\text{m/s})}{(1.0\times10^{6}\,\text{eV})(1.60\times10^{-19}\,\text{J/eV})} = 1.24\times10^{-12}\,\text{m} = 0.00124\,\text{nm}.$$

$$n = \frac{\lambda-\lambda_0}{\Delta\lambda} = \frac{(555\,\text{nm})-(0.00124\,\text{nm})}{9.24\times10^{-8}\,\text{nm}} = \boxed{6\times10^{9}\,\text{events}}$$

13.
37-35

The photon energy must be equal to the kinetic energy of the products plus the mass energy of the products. The mass of the positron is equal to the mass of the electron.

$$E_{\text{photon}} = K_{\text{products}} + m_{\text{products}}c^2 \rightarrow$$

$$K_{\text{products}} = E_{\text{photon}} - m_{\text{products}}c^2 = E_{\text{photon}} - 2m_{\text{electron}}c^2 = 2.67\,\text{MeV} - 2(0.511\,\text{MeV}) = \boxed{1.65\,\text{MeV}}$$

14.
37-37

The minimum energy necessary is equal to the rest energy of the two muons.

$$E_{\min} = 2mc^2 = 2(207)(0.511\,\text{MeV}) = \boxed{212\,\text{MeV}}$$

The wavelength is given by Eq. 37-5.

$$\lambda = \frac{hc}{E} = \frac{(6.63\times10^{-34}\,\text{J}\cdot\text{s})(3.00\times10^{8}\,\text{m/s})}{(1.60\times10^{-19}\,\text{J/eV})(212\times10^{6}\,\text{eV})} = \boxed{5.86\times10^{-15}\,\text{m}}$$

15.
37-38

Since $v < 0.001c$, the total energy of the particles is essentially equal to their rest energy. Both particles have the same rest energy of 0.511 MeV. Since the total momentum is 0, each photon must have half the available energy and equal momenta.

$$E_{\text{photon}} = m_{\text{electron}}c^2 = \boxed{0.511\,\text{MeV}} \quad ; \quad p_{\text{photon}} = \frac{E_{\text{photon}}}{c} = \boxed{0.511\,\text{MeV}/c}$$

16.
37-40

We find the wavelength from Eq. 37-7.

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{(6.63\times10^{-34}\,\text{J}\cdot\text{s})}{(0.23\,\text{kg})(0.10\,\text{m/s})} = \boxed{2.9\times10^{-32}\,\text{m}}$$

17.
37-42

We assume the electron is non-relativistic, and check that with the final answer. We use l

$$\lambda = \frac{h}{p} = \frac{h}{mv} \rightarrow v = \frac{h}{m\lambda} = \frac{(6.63\times10^{-34}\,\text{J•s})}{(9.11\times10^{-31}\,\text{kg})(0.21\times10^{-9}\,\text{m})} = 3.466\times10^{6}\,\text{m/s} = 0.01$$

Our use of classical expressions is justified. The kinetic energy is equal to the potential e change.

$$eV = K = \tfrac{1}{2}mv^2 = \frac{\tfrac{1}{2}(9.11\times10^{-31}\,\text{kg})(3.466\times10^{6}\,\text{m/s})^2}{(1.60\times10^{-19}\,\text{J/eV})} = 34.2\,\text{eV}$$

Thus the required potential difference is $\boxed{34\text{ V}}$

18.
37-43

The theoretical resolution limit is the wavelength of the electron. We find the wavelength from the momentum, and find the momentum from the kinetic energy and rest energy. We use the result fro Problem 94. The kinetic energy of the electron is 85 keV.

$$\lambda = \frac{hc}{\sqrt{K^2 + 2mc^2K}} = \frac{(6.63\times10^{-34}\,\text{J•s})(3.00\times10^{8}\,\text{m/s})}{(1.60\times10^{-19}\,\text{J/eV})\sqrt{(85\times10^{3}\text{eV})^2 + 2(0.511\times10^{6}\text{eV})(85\times10^{3}\text{eV})}}$$

$$= \boxed{4.1\times10^{-12}\,\text{m}}$$

19.
37-50

The final kinetic energy of the electron is equal to the negative change in potential energy of the electron as it passes through the potential difference. We compare this energy to the rest energy of the electron to determine if the electron is relativistic.

$$K = -q\Delta V = (1\text{e})(33\times10^{3}\ \text{V}) = 33\times10^{3}\,\text{eV}$$

Because this is greater than 1% of the electron rest energy, the electron is relativistic. We use Eq. 36-13 to determine the electron momentum and then Eq. 37-5 to determine the wavelength.

$$E^2 = \left[K + mc^2\right]^2 = p^2c^2 + m^2c^4 \Rightarrow p = \frac{\sqrt{K^2 + 2Kmc^2}}{c}$$

$$\lambda = \frac{h}{p} = \frac{hc}{\sqrt{K^2 + 2Kmc^2}} = \frac{1240\,\text{eV}\cdot\text{nm}}{\sqrt{(33\times10^{3}\text{eV})^2 + 2(33\times10^{3}\text{eV})(511\times10^{3}\text{eV})}} = 0.0066\,\text{nm}$$

Because $\lambda \ll 5$ cm, diffraction effects are negligible.