PHY2054 General Physics II

Section 590986

Prof. Douglas H. Laurence

Exam 3 (Chapters 28, 30, & 31)

July 31–August 1, 2018

Take-home

Name: SOLUTIONS

Instructions:

This exam is a take-home exam, due on **Wednesday August 1, 2018, by 11:59pm**. You must work on the exam by yourself, though you are, of course, allowed to access all lecture notes, your textbook, the internet, etc. You are not allowed to seek help from any tutors, professors, etc.; as I stated, you must work on the exam by yourself.

This exam is composed of **10 multiple choice questions** and **4 free-response problems**. To receive a perfect score (100) on this exam, 3 of the 4 free-response problems must be completed. The fourth free-response problem **may <u>not</u> be answered for extra credit**. Each multiple choice question is worth 2.5 points, for a total of 25 points, and each free-response problem is worth 25 points, for a total of 75 points. This means that your exam will be scored out of 100 total points, which will be presented in the rubric below. **Please do not write in the rubric below; it is for grading purposes only.**

Only scientific calculators are allowed – do not use any graphing or programmable calculators.

For multiple choice questions, no work must be shown to justify your answer and no partial credit will be given for any work. However, for the free response questions, **work must be shown to justify your answers.** The clearer the logic and presentation of your work, the easier it will be for the instructor to follow your logic and assign partial credit accordingly.

The exam begins on the next page. **The formula sheet is attached to the end of the exam.**

Exam Grade:

Multiple Choice	
Problem 1	
Problem 2	
Problem 3	
Problem 4	
Total	

MULTIPLE CHOICE QUESTIONS

1. Light traveling in water ($n = 1.33$) moves with what speed?

   (a) 1.5×10^8 m/s
   (b) 2.26×10^8 m/s
   (c) 3×10^8 m/s
   (d) 3.99×10^8 m/s

   $V = \frac{c}{n} = \frac{3 \times 10^8}{1.33} = 2.26 \times 10^8 \ m/s$

2. Light traveling in a vacuum has a wavelength of 550nm when it enters a pool of water ($n = 1.33$). What would the wavelength of the light be in the water?

   (a) 336nm
   (b) 414nm
   (c) 550nm
   (d) 732nm

   $f_1 = f_2 \Rightarrow \frac{V_1}{\lambda_1} = \frac{V_2}{\lambda_2}$; $V_1 = c$ (VACUUM), $V_2 = \frac{c}{n}$ (WATER)

   $\Rightarrow \frac{\cancel{c}}{\lambda_1} = \frac{\cancel{c}/n}{\lambda_2} \Rightarrow \lambda_2 = \frac{\lambda_1}{n} = \frac{550}{1.33} = 414 \text{nm}$

3. What is the maximum incident angle for light passing from olive oil ($n = 1.46$) into water ($n = 1.33$)?

   (a) 43^o
   (b) 49^o
   (c) 66^o
   (d) There is no maximum angle

   $\theta_c = \sin^{-1}\left(\frac{n_f}{n_i}\right) = \sin^{-1}\left(\frac{1.33}{1.46}\right) = 66^o$

4. If the work function of a metal is 5.7eV, what is the minimum frequency of light needed to free an electron from the metal?

   (a) 7.26×10^{-16} Hz
   (b) 1.38×10^{15} Hz
   (c) 8.60×10^{33} Hz
   (d) There is no minimum frequency

   $f_{MIN} = \frac{W_0}{h} = \frac{5.7 eV}{4.136 \times 10^{-15} eV \cdot s} = 1.38 \times 10^{15} Hz$

5. How much kinetic energy would an electron depart an aluminum plate ($W_0 = 4.1$ eV) if light with a wavelength of 100nm was shined on it?

   (a) 8.3 eV
   (b) 12.4 eV
   (c) 13.7 eV
   (d) 16.5 eV

   $K = \frac{hc}{\lambda} - W_0 = \frac{(1240 \ eV \cdot nm)}{(100 nm)} - (4.1 eV)$

   $= 8.3 eV$

6. A photon of wavelength 15×10^{-12} m hits an electron at rest, causing the electron to move. The photon bounces off the electron at some angle θ relative to its original direction. If its new wavelength is 16×10^{-12} m, what is θ?

   (a) 24^o
   (b) 36^o
   (c) 54^o
   (d) 66^o

   $\Delta\lambda = \lambda_f - \lambda_i = 16 \times 10^{-12} - 15 \times 10^{-12} = 1 \times 10^{-12}$

   $\Rightarrow \Delta\lambda = \frac{h}{m_e c}(1 - \cos\theta) \Rightarrow 1 - \cos\theta = \frac{\Delta\lambda}{(h/m_e c)}$

   $\Rightarrow \theta = \cos^{-1}\left(1 - \frac{\Delta\lambda}{h/m_e c}\right) = \cos^{-1}\left(1 - \frac{1 \times 10^{-12}}{2.426 \times 10^{-12}}\right) = 54^o$

7. If an electron, with a mass 9.11×10^{-31} kg, moves at a speed of 300 km/s, what is its de Broglie wavelength?

   (a) 0.39 nm
   (b) 2.42 nm
   (c) 390 nm
   (d) 2424 nm

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.626\times10^{-34}}{(9.11\times10^{-31})(300\times10^{3})}$$

$$= 2.42\times10^{-9}\,m = 2.42\,nm$$

8. What is the ionization energy of hydrogen from the $n = 3$ state?

   (a) 1.51 eV
   (b) 4.53 eV
   (c) 12.1 eV
   (d) 13.6 eV

$$\Delta E = (-13.6)\left(\frac{1}{\infty} - \frac{1}{3^2}\right) = 1.51\,eV$$

9. What frequency of light must an electron in hydrogen absorb to jump from the $n = 2$ state to the $n = 5$ state?

   (a) 2.86 Hz
   (b) 4.08 Hz
   (c) 6.91×10^{14} Hz
   (d) 9.86×10^{14} Hz

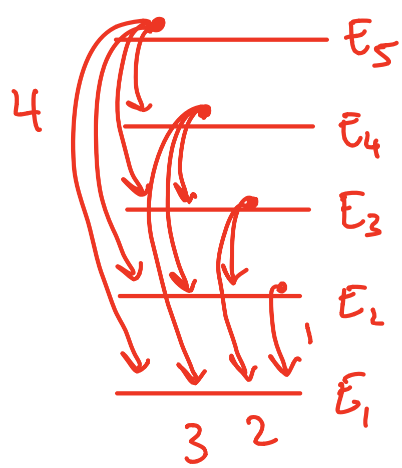
$$\Delta E = (-13.6eV)\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) = (-13.6eV)\left(\frac{1}{5^2} - \frac{1}{2^2}\right) = 2.86eV$$

PHOTON ENERGY IS 2.86 eV & $E = hf$

$$\Rightarrow f = \frac{E}{h} = \frac{(2.86)}{(4.136\times10^{-15})} = 6.91\times10^{14}\,Hz$$

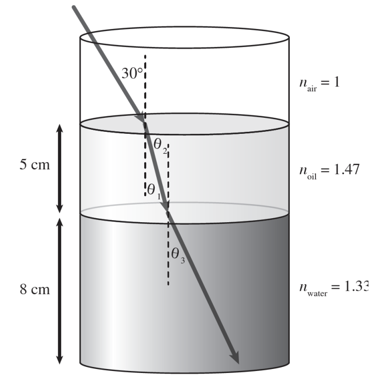
10. An electron absorbs a single photon to jump from the $n = 1$ state to the $n = 5$ state. How many different photons can be emitted?

   (a) 4
   (b) 5
   (c) 10
   (d) 24



$$4+3+2+1 = 10$$

FREE-RESPONSE PROBLEMS



1. Consider light passing from air ($n = 1$) into oil ($n = 1.47$) at an incident angle of 30^o, and then from the oil into water ($n = 1.33$), as shown in the figure above. In the figure, the angle θ_1 is the angle the light leaves the air-oil boundary with, θ_2 is the angle the light enters the oil-water boundary with, and θ_3 is the angle the light leaves the oil-water boundary with.

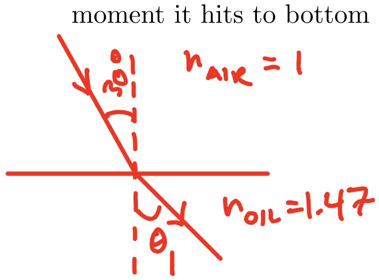
   (a) What is the angle θ_1?

   (b) What is the angle θ_2?

   (c) What is the angle θ_3?

   (d) As you can see in the figure, the light is moving horizontally (to the right) as it travels vertically (downward). How far horizontally does the light travel from the moment it enters the oil to the moment it hits to bottom of the container?

(a)

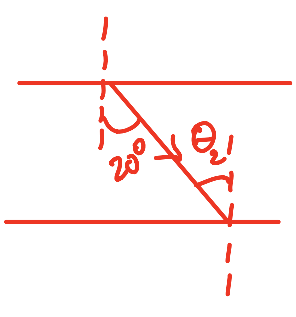


$n_i \sin\theta_i = n_f \sin\theta_f$

$\Rightarrow \theta_f = \sin^{-1}\left(\frac{n_i}{n_f}\sin\theta_i\right) = \sin^{-1}\left(\frac{1}{1.47}\sin 30°\right)$

$\Rightarrow \boxed{\theta_1 = 20°}$

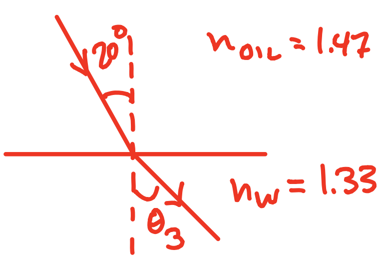
(b)



θ_2 & 20° ARE ALTERNATE INTERIOR ANGLES & THEREFORE EQUAL, SO

$\boxed{\theta_2 = 20°}$

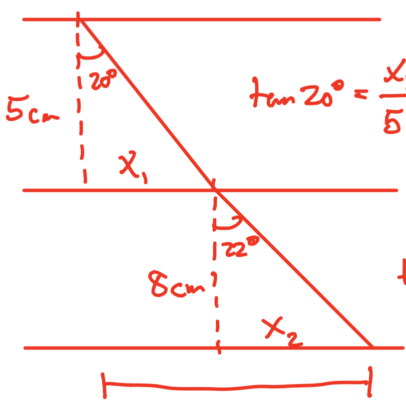
(c)



$\theta_f = \sin^{-1}\left(\frac{n_i}{n_f}\sin\theta_i\right) = \sin^{-1}\left(\frac{1.47}{1.33}\sin 20°\right)$

$\Rightarrow \boxed{\theta_3 = 22°}$

(d)



$$\tan = \frac{\text{OPPOSITE}}{\text{ADJACENT}}$$

$$\tan 20° = \frac{x_1}{5} \Rightarrow x_1 = 5 \tan 20° = 1.8 \text{ cm}$$

$$\tan 22° = \frac{x_2}{8} \Rightarrow x_2 = 8 \tan 22° = 3.2 \text{ cm}$$

$$d = x_1 + x_2 = 1.8 + 3.2 = 5 \text{ cm}$$

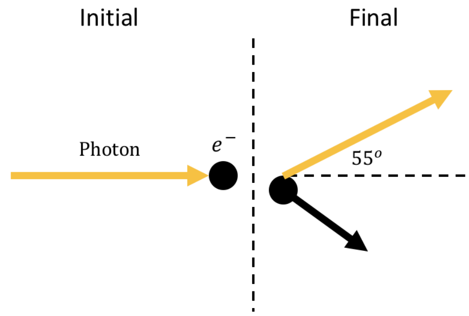
2. This problem is going to cover some of the important phenomena that led to the idea of a photon as a particle. The three main phenomena were blackbody radiation emission, the photoelectric effect, and Compton scattering.

(a) Briefly describe each phenomena (i.e. what blackbody radiation is, what the photoelectric effect is, and what Compton scattering is).

(b) What particle property had to be given to light in order to properly explain blackbody radiation?

(c) What particle property had to be given to light in order to properly explain the photoelectric effect?

(d) What particle property had to be given to light in order to properly explain Compton scattering?



3. Consider a photon with a wavelength of 20×10^{-12}m colliding with an electron at rest. After the collision, the electron moves away at some angle and the photon moves away at an angle of 55^o relative to its original direction of motion, as shown in the figure above.

(a) What was the initial energy of the photon?

(b) What is the wavelength of the photon after the collision?

(c) What is the energy of the photon after the collision?

(d) What is the kinetic energy of the electron after the collision? *Hint: this is an elastic collision, so energy is conserved.*

(a) $E_{ph} = \frac{hc}{\lambda}$; $hc = 1240 \text{ eV}\cdot\text{nm} \times \frac{10^{-9}\text{m}}{1\text{nm}} = 1.24\times10^{-6} \text{eV}\cdot\text{m}$

$$= \frac{(1.24 \times 10^{-6} \text{eV}\cdot\cancel{\text{m}})}{(20\times10^{-12}\cancel{\text{m}})} = \boxed{62{,}000 \text{ eV} = 62 \text{ keV}}$$

(b) $$\Delta\lambda = \frac{h}{m_e c}(1 - \cos\theta) = (2.426 \times10^{-12})(1 - \cos 55^o)$$
$$= 1 \times 10^{-12} \text{m}$$

$$\Rightarrow \lambda_f = \lambda_i + \Delta\lambda = 20 \times10^{-12} + 1\times10^{-12} = \boxed{21\times10^{-12}\text{m}}$$

(c) $$E_{ph} = \frac{(1.24 \times10^{-6})}{(21 \times 10^{-12})} = \boxed{59{,}048 \text{ eV} = 59.05 \text{ keV}}$$

(d) $E_i = E_{ph,i}$; $E_f = E_{ph,f} + K_e$

$$\Rightarrow K_e = E_{ph,i} - E_{ph,f} = 62 \text{ keV} - 59.05 \text{keV} = \boxed{2.95 \text{ keV}}$$

4. Consider the first 8 orbitals of hydrogen, i.e. $n = 1$, $n = 2$, ..., $n = 8$.

   (a) How many different photons could be emitted from a transition from $n = 8$ to a lower orbital?

   (b) What is the wavelength of a photon emitted for the transition $n = 6$ to $n = 3$?

   (c) What transition would produce the highest frequency photon? What is this frequency?

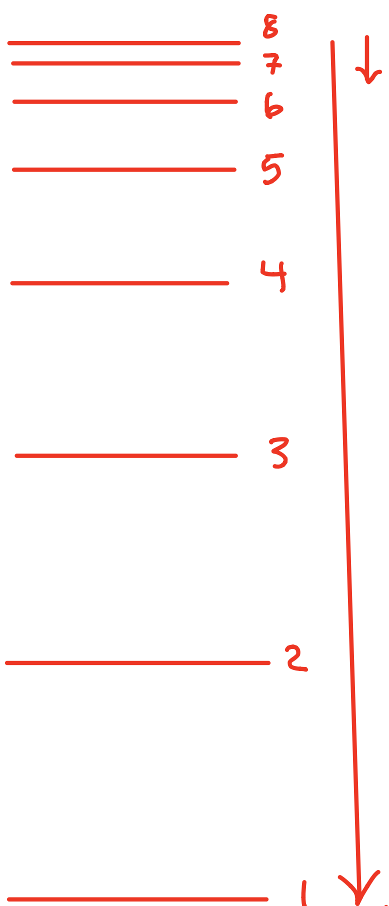
   (d) What transition would produce the lowest frequency photon? What is this frequency?

(a) # OF PHOTONS $= 7+6+5+4+3+2+1 = 28$

(b) $\Delta E_{6\to3} = (-13.6\,\text{eV})\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) = (-13.6)\left(\frac{1}{3^2} - \frac{1}{6^2}\right)$

$= -1.13\,\text{eV} \Rightarrow$ PHOTON HAS $E = +1.13\,\text{eV}$

$E_{ph} = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E} = \frac{(1240\,\cancel{\text{eV}}\cdot\text{nm})}{(1.13\,\cancel{\text{eV}})} = 1097\,\text{nm}$



SMALLEST ΔE
$\Rightarrow$ SMALLEST f

(c) $\Delta E_{8\to1} = (-13.6)\left(\frac{1}{1^2} - \frac{1}{8^2}\right) = -13.4\,\text{eV}$

$E_{ph} = \frac{h}{f} \Rightarrow f = \frac{E}{h} = \frac{13.4\,\text{eV}}{4.136\times10^{-15}\,\text{eV}\cdot\text{s}}$

$= 3.24\times10^{15}\,\text{Hz}$

(d) $\Delta E_{8\to7} = (-13.6)\left(\frac{1}{7^2} - \frac{1}{8^2}\right) = -0.065\,\text{eV}$

$\Rightarrow f = \frac{E}{h} = \frac{0.065}{4.136\times10^{-15}} = 1.57\times10^{13}\,\text{Hz}$

LARGEST ΔE
$\Rightarrow$ LARGEST f

FORMULA SHEET

- Vectors:

$$\vec{A}\cdot\vec{B} = AB\cos\theta = A_xB_x + A_yB_y + A_zB_z$$

$$\left|\vec{A}\times\vec{B}\right| = AB\sin\theta$$

- Physics I Formulae:

$$\sum \vec{F} = m\vec{a}$$

$$W = \vec{F}\cdot\Delta\vec{x}$$

$$W_{tot} = \Delta K$$

$$W_{cons} = -\Delta U$$

$$K = \frac{1}{2}mv^2$$

$$K_i + U_i = K_f + U_f$$

- Electric Forces and Fields:

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

$$\left.\begin{aligned} k &= 8.99\times 10^{9}\ \frac{\mathrm{Nm}^2}{\mathrm{C}^2} \\ \epsilon_0 &= 8.85\times 10^{-12}\ \frac{\mathrm{F}}{\mathrm{m}} \end{aligned}\right\}\ k = \frac{1}{4\pi\epsilon_0}$$

$$Q = Ne$$

$$F = k\frac{q_1q_2}{r^2}$$

$$\vec{F} = q\vec{E}$$

$$E = k\frac{q}{r^2}$$

$$\Phi_E = \vec{E}\cdot\vec{A}$$

$$\Phi_{tot} = \frac{q_{enc}}{\epsilon_0}$$

$$\lambda = \frac{Q}{L} \quad \text{or} \quad \sigma = \frac{Q}{A} \quad \text{or} \quad \rho = \frac{Q}{V} \quad \text{(charge densities)}$$

- Electric Potential Energy and Electric Potential:

$$U = k\frac{q_1q_2}{r}$$

$$\phi = k\frac{q}{r}$$

$$U = q\phi \quad \text{and} \quad \Delta U = q\Delta\phi$$

$$E_{av} = \frac{\Delta\phi}{\Delta x}$$

$$V = \Delta\phi$$

- Capacitance and Dielectrics:

$$Q = CV$$

$$\left.\begin{aligned} C &= \epsilon_0 \frac{A}{d} \\ E &= \frac{\sigma}{\epsilon_0} \end{aligned}\right\} \text{Parallel plate capacitors}$$

- Direct Current Circuits

$$R = \rho \frac{L}{A}$$

$$V_R = iR$$

$$P = Vi = i^2 R = \frac{V^2}{R}$$

$$\sum\nolimits_{\text{loop}} V = 0 \ \text{(Kirchhoff's Loop Rule)}$$

$$\sum i_{\text{in}} = \sum i_{\text{out}} \ \text{(Kirchhoff's Junction Rule)}$$

$$R_{\text{eq}} = R_1 + R_2 + R_3 + ... \ \text{(series)}$$

$$\frac{1}{R_{\text{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ... \ \text{(parallel)}$$

- Magnetism

$$\mu_0 = 4\pi \times 10^{-7} \ \frac{\text{Tm}}{\text{A}}$$

$$\vec{B} = \frac{\mu_0}{4\pi} \frac{q\vec{v} \times \vec{r}}{r^3} \ \text{(point charge)}$$

$$B = \frac{\mu_0 i}{2\pi r} \ \text{(long wire)}$$

$$B = \frac{\mu_0 i}{2R} \ \text{(center of a loop)}$$

$$B = \mu_0 \frac{N}{L} i = \mu_0 n i \ \text{(center of a solenoid)}$$

$$\vec{F}_B = q\vec{v} \times \vec{B} \ \text{(point charge)}$$

$$\vec{F}_B = i\vec{l} \times \vec{B} \ \text{(wire)}$$

- Electromagnetic Induction

$$\Phi_B = \vec{B} \cdot \vec{A} = BA\cos\theta$$

$$\mathcal{E}_{\text{ind}} = -\frac{\Delta \Phi_B}{\Delta t}$$

- Electromagnetic Waves

$$c = 3 \times 10^8 \text{ m/s}$$
$$h = 6.626 \times 10^{-34} \text{ Js} = 4.136 \times 10^{-15} \text{ eVs}$$
$$c = \lambda f$$
$$E = hf = \frac{hc}{\lambda}$$
$$v = \frac{c}{n}$$
$$n_i \sin\theta_i = n_f \sin\theta_f$$
$$\theta_c = \sin^{-1}\left(\frac{n_f}{n_i}\right)$$

- Quantum Mechanics

$$\hbar = \frac{h}{2\pi} = 1.055 \times 10^{-34} \text{ Js} = 6.582 \times 10^{-16} \text{ eVs}$$
$$hc = 1.986 \times 10^{-25} \text{ Jm} = 1240 \text{ eV} \cdot \text{nm}$$
$$K = hf - W_0 \text{ (photoelectric effect)}$$
$$\Delta\lambda = \frac{h}{m_e c}(1 - \cos\theta) \text{ (Compton scattering)}$$
$$\text{with } \frac{h}{m_e c} = 2.426 \times 10^{-12} \text{ m}$$
$$\lambda = \frac{h}{p} \text{ (de Broglie wavelength)}$$

For the following, $n = 1, 2, 3, ...$

$$L = rp = n\hbar \text{ (angular momentum quantization)}$$
$$r = n^2 a_0 \text{ (orbit quantization)}$$
$$\text{with } a_0 = 5.29 \times 10^{-11} \text{ m}$$
$$v = \frac{ke^2}{n\hbar} \text{ (orbital velocity quantization)}$$
$$E = \frac{-13.6 \text{ eV}}{n^2}$$
$$\Delta E = (-13.6 \text{ eV})\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$