

# Homework #3

PHYS 4D: Modern Physics

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## 1 Questions

### 1.1 Question 1

How are the threshold frequency  $f_0$  and wavelength  $\lambda_0$  for the photoelectric effect related to the work function  $W$  of a metal?

#### 1.1.1 Solution

The work function of a metal is related to the threshold frequency and wavelength separately, since they are dependant on each other.

$$W = hf_0 - (KE)_{\max} \quad (1)$$

$$W = \frac{hc}{\lambda_0} \quad (2)$$

### 1.2 Question 2

Write down an equation showing how the maximum kinetic energy of photoelectrons depends upon the wavelength of the incident light and the work function of the metal.

#### 1.2.1 Solution

I'm taking this from the Basic Equations of this chapter.

$$(KE)_{\max} = \frac{hc}{\lambda} - W \quad (3)$$

### **1.3 Question 3**

What would be the work function of a metal with threshold wavelength of 400 nm?

#### **1.3.1 Solution**

$$W = \frac{hc}{\lambda_0} = \frac{1240 \text{ eV} \cdot \text{nm}}{400 \text{ nm}} = \boxed{3.1 \text{ eV}} \quad (4)$$

### **1.4 Question 4**

Would photoelectrons be emitted from a metal if the wavelength of the incident light were longer than the threshold wavelength?

#### **1.4.1 Solution**

The minimum in light is set by the frequency. This means that the maximum is given in the wavelength. This means that if it were longer, no photoelectrons would be emitted.

### **1.5 Question 6**

What causes the dark lines in the solar spectra?

#### **1.5.1 Solution**

These would be the colors of light waves that are absorbed by atoms somewhere between the sun and the earth.

### **1.6 Question 7**

Suppose that an atom makes a transition from an energy level  $E_2$  to an energy level  $E_1$  emitting light. How is the light's frequency  $f$  related to the difference of energy,  $E_2 - E_1$  ?

### 1.6.1 Solution

The frequency is directly proportional to the difference of energy.

$$f = \frac{E_2 - E_1}{h} \quad (5)$$

## 1.7 Question 8

Write down a formula for the energy levels of hydrogen.

### 1.7.1 Solution

Let's use Rybaek's Rydberg's Equation.

$$E = -R \frac{hc}{n} = -\frac{13.6 \text{ eV}}{n^2} \quad (6)$$

## 1.8 Question 11

What is the energy of the hydrogen atom in the  $n = 4$  state?

### 1.8.1 Solution

Use Rydberg's equation.

$$E_4 = -\frac{13.6 \text{ eV}}{4^2} = \boxed{-0.8375 \text{ eV}} \quad (7)$$

## 1.9 Question 12

What photon energy would be required to ionize a hydrogen atom in the  $n = 5$  state?

### 1.9.1 Solution

Use Rydberg's equation.

$$-E_5 = \frac{13.6 \text{ eV}}{5^2} = \boxed{0.544 \text{ eV}} \quad (8)$$

## 1.10 Question 15

What model of light can be used to describe the *Compton effect*?

### 1.10.1 Solution

The particle model can be used to describe the Compton effect.

## 1.11 Question 16

What is Bragg's law for X-ray diffraction?

### 1.11.1 Solution

Bragg's law defines the requirements for constructive interference to occur between two X-rays of wavelength  $\lambda$  hitting two lattices of a crystal a distance  $d$  from each other at an angle  $\theta$  with the perpendicular. It includes a coefficient  $n \in \mathbb{N}$ .

$$2d \sin(\theta) = n\lambda \quad (9)$$

## 1.12 Question 17

How are the momentum and the wavelength of a particle related?

### 1.12.1 Solution

The momentum of a particle is defined by its energy, which is defined by its frequency, which is directly related to its wavelength.

$$p = \frac{E}{c} = \frac{hf}{c} = \frac{h\nu}{\lambda} = \frac{h}{\lambda} \quad (10)$$

## 1.13 Question 18

Express the momentum of an electron in terms of the angular wave vector  $k$ .

### 1.13.1 Solution

Use the equation from earlier and relate the wavelength and wave number.

$$\lambda = \frac{2\pi}{k}; \hbar = \frac{h}{2\pi} \quad (11)$$

$$p = \frac{h}{\lambda} = \frac{hk}{2\pi} = \hbar k \quad (12)$$

## 1.14 Question 19

How would the de Broglie wavelength of an electron change if its velocity were to double?

### 1.14.1 Solution

If the electron's velocity doubles, its momentum doubles. Since wavelength is inversely related to momentum, a doubled momentum would lead to a halved wavelength.

## 1.15 Question 20

Describe the interference pattern produced when a beam of light having a single wavelength is incident upon two slits?

### 1.15.1 Solution

You would wind up with a pattern of light and dark spots (corresponding to where photons do and do not land). This is known as the two-slit experiment.

## 2 Problem 1

Calculate the energy of the photons for light having a wavelength  $\lambda = 200 \text{ nm}$ .

### 2.1 Solution

## 3 Problem 2

Suppose that a 100 Watt beam of light is incident upon a metal surface. If the light has a wavelength  $\lambda = 200 \text{ nm}$ , how many photons strike the surface

every second? (Hint: Using the power of the beam, find how much energy is incident upon the surface every second.)

### 3.1 Solution

## 4 Problem 4

What will the maximum kinetic energy of the emitted photoelectrons be when ultraviolet light having a wavelength of 200 nm is incident upon the following metal surfaces?

- a) Na
- b) Al
- c) Ag

### 4.1 Solution

## 5 Problem 6

Light having a wavelength of 460 nm is incident on a cathode, and electrons are emitted from the metal surface. It is observed that the electrons may be prohibited from reaching the anode by applying a stopping potential of 0.72 eV. What is the work function of the metal in the cathode?

### 5.1 Solution

## 6 Problem 7

By how much would the stopping potential in the previous problem increase if the wavelength of the radiation were reduced to 240 nm?

## **6.1 Solution**

### **7 Problem 11**

An electron in the  $n = 5$  state of hydrogen makes a transition to the  $n = 2$  state. What are the energy and wavelength of the emitted photon?

## **7.1 Solution**

### **8 Problem 16**

Ultraviolet light of wavelength 45.0 nm is incident upon a collection of hydrogen atoms in the ground state. Find the kinetic energy and the velocity of the emitted electrons.

## **8.1 Solution**

### **9 Problem 20**

What potential difference must electrons be accelerated through to have the same wavelength as 40 keV X-rays?

## **9.1 Solution**

### **10 Problem 21**

Electrons, protons, and neutrons have wavelengths of 0.01 nm. Calculate their kinetic energies.

## **10.1 Solution**