Modern Physics: Homework 1

Due: 1 February 2021

1 Intensity of light

A laser produces a beam with power 5.0 mW. The beam emerging from the laser has an approximately circular cross section with diameter 2.0 mm. The beam passes through a lens which increases its diameter so that when it hits a screen it is 30 mm wide. Assume that, at any stage, the intensity of the beam is uniform across its width and that the lens does not absorb any light. *(231S21)*

a) Determine the energy that arrives at the lens in 4.0 ms.

b) Determine the energy that arrives at the screen in 4.0 ms.

c) Suppose that there is a small hole in the screen with diameter 1.0 mm. Determine the energy passing through this hole in 4.0 ms.

d) Determine the ratio of the intensity of the light at the moment that it hits the screen to the intensity before passing through the lens. Recall that the intensity of light is the power per unit area.

e) Determine the ratio of the intensity of the light that passes though the hole in the screen to the intensity before passing through the lens.

2 Photo-emission from metals

The wavelength of violet light is 434×10^{-9} m and that of red light 678×10^{-9} m. Which is more likely to be able to dislodge electrons from a metal? Explain your answer. *(231S21)*

3 Photoelectric effect

The work functions (the quantity ϕ in the equation for photoelectric effect) for various elements are given[a] in table 1. Recall that $1\,\text{eV} = 1.6 \times 10^{-19}$ J. *(231S21)*

[a] Ref: P.A. Tipler and R.A. Llewellyn, *Modern Physics*, 4th ed, Freeman.

Element	ϕ in eV
Sodium	2.28
Aluminum	4.08
Copper	4.7
Gold	5.1
Platinum	6.35

Table 1: Photoelectric work functions.

a) Experiments show that, for a given element, a minimum frequency of light is required to eject electrons. What is the kinetic energy of the electrons ejected when the element is illuminated with the minimum frequency light? How is the energy of each photon of light related to the work function in this case?

b) For each element listed in table 1, determine the minimum frequency of light which results in ejection of electrons.

c) Light of frequency 1.2×10^{15} Hz is to be used in a photoelectric effect experiment. For which elements listed in table 1 will it result in ejection of electrons?

4 Photo-emission from copper

Suppose that photoelectric emission from copper is investigated using the following sources of light:

1. a laser emitting (bright) light with frequency 0.6×10^{15} Hz at power $5\,\text{mW} = 5 \times 10^{-3}$ W,
2. a laser emitting (dim) light with frequency 0.6×10^{15} Hz at power $0.2\,\text{mW} = 2 \times 10^{-4}$ W,
3. a laser emitting (bright) light with frequency 1.5×10^{15} Hz at power 5 mW, and
4. a laser emitting (dim) light with frequency 1.5×10^{15} Hz at power 0.2 mW.

Experimental data indicates that it takes energy 7.52×10^{-19} J to eject any electrons from the copper. The laser beams each effectively illuminate 10^{16} copper atoms. Recall that the power of the laser beams is the amount of energy they produce in one second. *(231S21)*

a) Describe qualitatively the process of emission of electrons in terms of the classical picture of light waves interacting with the electrons in the copper.

b) Using the classical picture of light, determine how much energy falls on one atom per second and how long it would take to emit one electron from the atom for each of the sources. How do these compare to experimental observations for photoelectric emission?

c) Describe qualitatively the process of emission of electrons in terms of the modern picture of photons interacting with the electrons in the copper.

d) Which of the above sources will result in emission of electrons?

e) In cases where electrons are emitted, what differences would be noticeable, using the appropriate instruments, for the various sources listed above?

5 Photographic film

The critical ingredient in black and white photographic film is silver bromide. An individual silver bromide molecule changes appearance when a photon collides with it and breaks a particular molecular bond. Exposed film hosting an image can be handled in a darkroom illuminated with red light without further exposure (and destruction of the image) whereas blue light will expose the film. in the following explain all of your answers. *(231S21)*

a) Can you explain why the color of the light makes such a crucial difference?

b) Suppose that the two light sources provide red light of exactly the same wavelength but different intensities. What differences, if any, would these produce in exposure of the film?

c) Could one avert the detrimental exposure by using blue light of a lower intensity?

d) The minimum energy needed to break the molecular bond is 1.09×10^{-19} J. Which frequencies and wavelengths of light are safe to use in the darkroom?

6 Photons emitted from a laser

A HeNe laser produces light with wavelength 632.8 nm. *(231S21)*

a) Suppose that the laser produces 1.6×10^{16} photons per second. Determine the power provided by the laser.

b) The laser light passes through an optical attenuator that reduces its intensity. The intensity of the light that passes through the attenuator is 0.0010 times the intensity of the light that arrives at the attenuator. Determine the number of photons that pass through the attenuator every second.

7 Photon detection

Photons can be detected by devices that use the photoelectric effect. One example of this is a photomultiplier. An incident photon hits a special metal surface and ejects an electron by the photoelectric effect. This electron is then accelerated with electric fields and collides with a piece of metal. Multiple electrons are then ejected from this piece of metal. These are accelerated toward yet another piece of metal. This continues through several such amplification stages until a detectable number of electrons are produced (for a description and diagram see Ch. 2 of the manual at `https://org.coloradomesa.edu/~dacollin/teaching/2021Spring/Phys231/HamamatsuPMT.pdf`). These are converted into a current.

Suppose that laser light with wavelength 632.8 nm and power 0.010 mW is incident on a photomultiplier. Assume that at this wavelength the device has an efficiency of 15% (i.e it only detects this fraction of incident photons) and that it produces 10^6 electrons per photon that it detects. How many electrons does the device produce per second? What electrical current would this give? *(231S21)*

Note: This problem contains many simplifications about the actual workings of such devices.