LibreTexts

4.5: Activities

Beams of different frequency electromagnetic radiation are described below.

A gamma ray
B green light
C x-ray
D yellow light
E AM radio wave
F FM radio wave

a. Rank these beams on the basis of their frequency.

Largest 1. _____ 2. _____ 3. _____ 4. _____ 5. _____ 6. _____ Smallest

_____ The ranking cannot be determined based on the information provided.

Explain the reason for your ranking:

b. If each beam has the same total energy, rank these beams on the number of photons in each beam.

Largest 1. _____ 2. _____ 3. _____ 4. _____ 5. _____ 6. _____ Smallest

_____ The ranking cannot be determined based on the information provided.

Explain the reason for your ranking:

c. If each beam has the same number of photons, rank these beams on their total energy.

Largest 1. _____ 2. _____ 3. _____ 4. _____ 5. _____ 6. _____ Smallest

_____ The ranking cannot be determined based on the information provided.

Explain the reason for your ranking:

The six metals listed below have the work functions indicated.

Metal Work Function (eV)
A aluminum 4.1
B beryllium 5.0
C cesium 2.1
D magnesium 3.7
E platinum 6.4
F potassium 2.3

a. Rank these metals on the basis of their threshold frequency.

Largest 1. _____ 2. _____ 3. _____ 4. _____ 5. _____ 6. _____ Smallest

_____ The ranking cannot be determined based on the information provided.

Explain the reason for your ranking:

b. Rank these metals on the basis of the maximum wavelength of light needed to free electrons from their surface.

Largest 1. _____ 2. _____ 3. _____ 4. _____ 5. _____ 6. _____ Smallest

_____ The ranking cannot be determined based on the information provided.

Explain the reason for your ranking:

c. Each metal is illuminated with 400 nm (3.10 eV) light. Rank the metals on the basis of the maximum kinetic energy of the emitted electrons. (If no electrons are emitted from a metal, the maximum kinetic energy is zero, so rank that metal as smallest.)

Largest 1. _____ 2. _____ 3. _____ 4. _____ 5. _____ 6. _____ Smallest

_____ The ranking cannot be determined based on the information provided.

Explain the reason for your ranking:

Six different light sources of different intensity (I) and frequency (f) are directed onto identical sodium surfaces. Sodium has a threshold frequency of 0.55 x 1015 Hz.

I (W/m2) f (x 1015 Hz)
A 1.0 1.0
B 2.0 0.5
C 1.0 2.0
D 0.5 2.0
E 4.0 0.5
F 0.5 1.0

a. Which of the sodium surfaces emit electrons?

b. Of the surfaces that emit electrons, rank the scenarios on the basis of the maximum kinetic energy of the emitted electrons.

Largest 1. _____ 2. _____ 3. _____ 4. _____ 5. _____ 6. _____ Smallest

_____ The ranking cannot be determined based on the information provided.

Explain the reason for your ranking:

c. Of the surfaces that emit electrons, rank the scenarios on the basis of the stopping potential needed to “stop” the emitted electrons.

Largest 1. _____ 2. _____ 3. _____ 4. _____ 5. _____ 6. _____ Smallest

_____ The ranking cannot be determined based on the information provided.

Explain the reason for your ranking:

The line below represents the maximum kinetic energy of photoelectrons emitted from sodium metal as a function of the frequency of the incident light.

a. If the intensity of the light striking the sodium metal was doubled, and the experiment re-performed, sketch and label as (a) the line that would represent the results of the experiment.

b. If a metal having half the work function of sodium was used in the experiment, and the experiment re-performed, sketch and label as (b) the line that would represent the results of the experiment.

c. What feature of the graph (i.e., slope, y-intercept, x-intercept, etc.) represents the work function?

d. What feature of the graph (i.e., slope, y-intercept, x-intercept, etc.) represents Planck’s constant?

A bar chart for the energy of the each incident photon, the kinetic energy of each emitted electron, and the work function of the metal surface is shown for a specific run of a photoelectric effect experiment.

For each change in the experiment listed below, construct a bar chart that illustrates the changes in each of the variables.

1. Use a brighter light source

2.Use a higher frequency light source

3. Use a metal with a lower threshold frequency

4. Use a metal with a work function greater than the photon energy

For each of the following experimental observations, select the correct choice from below:

A Can best be explained by thinking of light as a wave
B Can best be explained by thinking of light as a stream of particles
C Can be explained by either conception of light
D Cannot be explained by either conception of light

________ 1. In the photoelectric effect experiment, the current is directly proportional to the intensity of the incident light.

________ 2. In the photoelectric effect experiment, a threshold frequency exists below which no electrons are emitted.

________ 3. In the double slit experiment, light spreads out as it exits each hole of the apparatus.

________ 4. In the Compton scattering experiment, the wavelength of scattered light is longer than that of the incident light by an amount dependent on scattering angle.

________ 5. In the photoelectric effect experiment, the stopping voltage is independent of the intensity of the incident light.

________ 6. In the double slit experiment, a pattern of many alternating bright and dark spots appears on the screen opposite the slits.

________ 7. In the Compton scattering experiment, light is scattered from electrons to all angles.

________ 8. In the photoelectric effect experiment, electrons are emitted immediately after turning on the light, even at very low intensity.

________ 9. In the photoelectric effect experiment with constant light intensity, the electrons emitted from different metals require different stopping voltages.

________ 10. Light can pass through certain objects (like glass) but not through other objects (like concrete).

The image below shows the typical set-up for a Compton scattering experiment and the number of photons detected at different wavelengths with the photon detector at 900 from the initial beam direction. The incident photon wavelength is .

a. The peak present at ' corresponds to the result expected from the Compton scattering formula. Why is there also a peak present at the initial photon wavelength? (Hint: These photons are also scattered from the target.)

b. The peaks present in actual data have a width, i.e., not all of the photons scattered from electrons are scattered to exactly '. Why is there a spread in wavelength of the scattered photons?

c. Which of the two graphs below corresponds to the data collected with the detector at 450? Explain your reasoning.

The image below shows the photon cross sections for lead.

a. Using a pair of vertical lines, divide the graph into the three regions where the photoelectric effect, Compton scattering, and pair production are the dominant processes. Label these regions.

b. Using a dashed vertical line, indicate the energy at which photons would penetrate deepest into a lead target.

c. At the energy at which pair production becomes the dominant process, approximately how much more likely is pair production than the photoelectric effect?

d. Clearly explain why the cross section for the photoelectric effect has sharp "knife edge" jumps. Which lead electrons are beginning to absorb photons at the rightmost of these jumps?

e. Clearly explain why coherent scattering is much more likely than incoherent scattering at low energies. (Hint: Consider the photon wavelength and the size of a lead atom.)

f. Clearly explain why the pair production cross sections abruptly disappear at around 1 MeV.

a. How many photons per second are emitted by a 10 kW FM transmitter broadcasting at 89.7 MHz?
b. How many photons per second are emitted by a 5.0 mW, 634 nm laser?
c. Approximately how far apart are the individual photons in the laser beam described in (b), assuming the beam has negligible cross-sectional area?

Mathematical Analysis

When the human eye is fully dark-adapted, it requires approximately 1000 photons per second striking the retina for an object to be visible. These photons enter the eye through the approximately 3 mm diameter pupil.
a. Approximately how far apart are the individual photons striking our eye in the situation above?
b. The sun radiates at about 3.9 x 1026 W, with peak emission around 500 nm. Approximately how many photons per second are emitted by the sun?

c. Assuming these photons are radiated equally in all directions and very few are absorbed by intervening materials, approximately how far away could a star like the sun be and still be visible to humans?

Mathematical Analysis

Lead is illuminated with UV light of wavelength 250 nm. This results in a stopping potential of 0.82 V.
a. What is the work function for lead?
b. What is the stopping potential when lead is illuminated with 200 nm light?
c. What is the threshold frequency for lead?

Mathematical Analysis

When cesium is illuminated with 500 nm light the stopping potential is 0.57 V.
a. What is the work function for cesium?
b. For what wavelength light is the stopping potential 1.0 V?
c. What is the threshold wavelength for cesium?

Mathematical Analysis

A 190 mW laser operating at 650 nm is directed onto a photosensitive metal with work function 0.7 eV.
a. How many photons per second are emitted by the laser?
b. What is the maximum kinetic energy of the ejected electrons?
c. If 15% of the laser light is absorbed (with 85% reflected), what is the electron current in this experiment?

Mathematical Analysis

Light of wavelength 500 nm is incident on a photosensitive metal. The stopping potential is found to be 0.45 V.
a. Find the maximum kinetic energy of the ejected electrons.
b. Find the work function of the metal.
c. Find the cutoff wavelength of the metal.

Mathematical Analysis

The photoelectric effect involves the absorption of a photon by an electron bound in a metal. Show that it is impossible for a free electron at rest to absorb a photon. (Hint: Show that combining the conservation of \energy and the conservation of momentum for a free electron absorbing a photon results in a contradiction.)

Mathematical Analysis

A 0.03 nm photon collides with an electron at rest. After the collision, the photon is detected at 400 relative to its initial direction of travel.
a. Find the energy of the scattered photon.
b. Find the kinetic energy of the scattered electron.
c. Find the angle of the scattered electron.

Mathematical Analysis

An 800 keV photon collides with an electron at rest. After the collision, the photon is detected with 650 keV of energy.
a. Find the angle of the scattered photon.
b. Find the kinetic energy of the scattered electron.
c. Find the angle of the scattered electron.

Mathematical Analysis

A 0.01 nm photon collides with an electron at rest. After the collision, the photon is detected with 0.1 MeV of energy.

a. Find the angle of the scattered electron.

b. Find the velocity of the scattered electron.

Mathematical Analysis

In a Compton scattering experiment, it is noted that the maximum energy transferred to an electron is 45 keV. What was the initial photon energy used in the experiment?

Mathematical Analysis

In a symmetric collision, the scattering angle of the photon and electron are equal. If the incoming photon has 1.0 MeV of energy, and the scattering is symmetric, find the scattering angle.

Mathematical Analysis

A 2.0 MeV photon interacts with a carbon nucleus and creates an electron-positron pair. The electron and positron travel perpendicular to the initial direction of travel of the photon.

a. Find the kinetic energy of the electron and positron assuming the nucleus is at rest after the interaction.

b. Find the kinetic energy of the carbon nucleus needed to ensure momentum conservation. Would this amount of kinetic energy greatly affect the result in part a?

Mathematical Analysis

A 1.5 MeV photon interacts with a carbon nucleus and creates an electron-positron pair. The electron travels parallel and the positron antiparallel, at equal speeds, to the initial direction of travel of the photon.

a. Find the kinetic energy of the electron and positron assuming the nucleus is at rest after the interaction.

b. Find the kinetic energy of the carbon nucleus needed to ensure momentum conservation. Would this amount of kinetic energy greatly affect the result in part a?

Mathematical Analysis

A photon interacts with a lead nucleus and creates a proton-antiproton pair. The proton travels parallel and the antiproton antiparallel, both at 0.4c, to the initial direction of travel of the photon.

a. Find the kinetic energy of the proton and antiproton assuming the nucleus is at rest after the interaction.

b. Find the kinetic energy of the lead nucleus needed to ensure momentum conservation. Would this amount of kinetic energy greatly affect the result in part a?

Mathematical Analysis

A 1.8 MeV photon interacts with a lead nucleus and creates an electron-positron pair. The electron and positron travel at 350 from the initial direction of travel of the photon.

a. Find the kinetic energy of the electron and positron assuming the nucleus is at rest after the interaction.

b. Find the kinetic energy of the lead nucleus needed to ensure momentum conservation. Would this amount of kinetic energy greatly affect the result in part a?

Mathematical Analysis

A 1.8 MeV photon interacts with a hydrogen nucleus and creates an electron-positron pair. The electron and positron travel at 350 from the initial direction of travel of the photon.

a. Find the kinetic energy of the electron and positron assuming the nucleus is at rest after the interaction.

b. Find the kinetic energy of the hydrogen nucleus needed to ensure momentum conservation. Would this amount of kinetic energy greatly affect the result in part a?

Mathematical Analysis

Photons are incident on a 1.0 cm thick aluminum target.
a. If the incident energy is 1.0 keV, what percentage of the photons will undergo the photoelectric effect?
b. If the incident energy is 1.0 MeV, what percentage of the photons will undergo the photoelectric effect?
c. If the incident energy is 1.0 MeV, what percentage of the photons will be stopped or scattered?

Mathematical Analysis

Photons are incident on a very thick aluminum target.
a. At what energy will the beam penetrate deepest into the aluminum?
b. At the above energy, what thickness is needed to decrease the beam intensity by 50%?
c. At the above energy, what is the dominant photon process? What percentage of photons undergo this process?

Mathematical Analysis

Photons are incident on a very thick “depleted” uranium target.
a. At what energy will the beam penetrate deepest into the uranium?
b. At the above energy, what thickness is needed to decrease the beam intensity by 50%?
c. At the above energy, what is the dominant photon process? What percentage of photons undergo this process?

Mathematical Analysis

Equal intensity photon beams are incident on slabs of iron and lead.
a. At 1.0 MeV, find the thickness of lead needed to provide the same attenuation as 10 cm of iron.
b. At 100 MeV, find the thickness of lead needed to provide the same attenuation as 10 cm of iron.

Mathematical Analysis

a. For a 1.0 keV photon beam, find the thickness of air needed to decrease the beam intensity by 99%?
b. For a 100 MeV photon beam, find the thickness of air needed to decrease the beam intensity by 99%?

Mathematical Analysis

a. For a 1.0 keV photon beam, find the thickness of water needed to decrease the beam intensity by 99%?
b. For a 100 MeV photon beam, find the thickness of water needed to decrease the beam intensity by 99%?

Mathematical Analysis

Diagnostic x-rays have energy of around 100 keV. Imagine getting an x-ray for a broken arm. Model the non-bony part of the arm as a 5 cm thick bag of water.
a. What percentage of x-rays are absorbed by the non-bony part of the arm?
b. What percentage of x-rays are scattered by the non-bony part of the arm?
c. With all of these scattered x-rays flying around, you may want to wear a 1.0 cm thick lead apron to protect yourself. What percentage of x-rays (incident or scattered) are absorbed by the lead apron?

Mathematical Analysis

1.0 MeV photons are incident on a lead target. What is the probability per atom that a photon will be absorbed? (Hint: Consider a 1.0 cm thick target and use the density and molar mass of lead.)