Modern Physics Practice Items

1. Often observed in radio astronomy at a characteristic frequency of 1420.41 MHz, the precession frequency of neutral hydrogen atoms, the microwaves of the hydrogen line come from the atomic transition of an electron between the two hyperfine levels of the hydrogen 1 s ground state that have an energy difference of ≈ 5.87μeV. What is the wavelength in a vacuum of this electromagnetic radiation?

- **A.** 4.1×10^{-15} m
- **B.** 21 μm
- **C.** 21 cm
- **D.** 4.7 m

2. What is the energy carried by a single photon of yellow light, $\lambda = 505$ nm ($h = 6.63 \times 10^{-34}$ J·s)?

- **A.** 3.5×10^{-40} J
- **B.** 3.9×10^{-19} J
- **C.** 7.6×10^{-12} J
- **D.** 1.2×10^{-10} J

3. The same X-rays that can eject photoelectrons from zinc metal may also be diffracted by the surface of ZnS crystal. Which of the following principles does this demonstrate?

- **A.** Electrons may be diffracted.
- **B.** Zinc metal exhibits Rayleigh scattering of incident X-rays while ZnS does not.
- **C.** The work function for a pure metal is higher than it is for an ore of the metal.
- **D.** Light exhibits both particle and wave properties.

4. Consider two monochromatic sources of light A and B. The frequency of the electromagnetic waves emitted by source A and the power of source A are both half that of source B. In the time it takes source A to emit *n* number of photons, how many photons does source B emit?

- **A.** ¼ *n*
- **B.** *n*
- **C.** 2*n*
- **D.** 4*n*

5. A 100 W HeNe laser emits coherent yellow light ($\lambda = 598$ nm). Assuming light production were 100% efficient, how many photons does it produce per second?

- **A.** 6.0×10^{4}
- **B.** 3.0×10^{20}
- **C.** 6.0×10^{23}
- **D.** 2.5×10^{41}

6. What will be the result of measuring the distance from a hydrogen electron in its ground state to the nucleus?

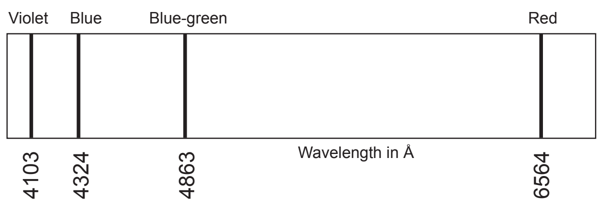
- **A.** the Bohr radius
- **B.** a set of distances corresponding to the Balmer series of spectral emissions
- **C.** a distance equal to the radius of the nucleus
- **D.** the Bohr radius, most likely, but a range of distances is possible

7. A spacecraft exposed to sunlight will develop a positive charge. This is most likely due to

- **A.** the photoelectric effect
- **B.** pair production
- **C.** quantum tunneling
- **D.** the solar wind

8. Below is a portion of the line spectrum in the visible region for hydrogen. The red line results from photons released in the electronic transition from n = 3 to n = 2. What is the value of the energy involved in this electronic transition? ($h = 6.63 \times 10^{-34}$ J·s)

A. 3.01×10^{-20} J
B. 1.00×10^{-19} J
C. 3.01×10^{-19} J
D. 4.84×10^{-19} J



9. In a 1923-27 experiment by Clinton Davisson and Lester Germer, electrons, scattered by the surface of a crystal of nickel metal, displayed a diffraction pattern. This confirmed the hypothesis, advanced by Louis de Broglie in 1924, of

A. quantized atomic energy levels
B. the uncertainty principle
C. wave-particle duality
D. photon theory

10. Which of the following particles would have the shortest de Broglie wavelength traveling at 1.5×10^4 m/s?

A. neutrino
B. positron
C. proton
D. α particle

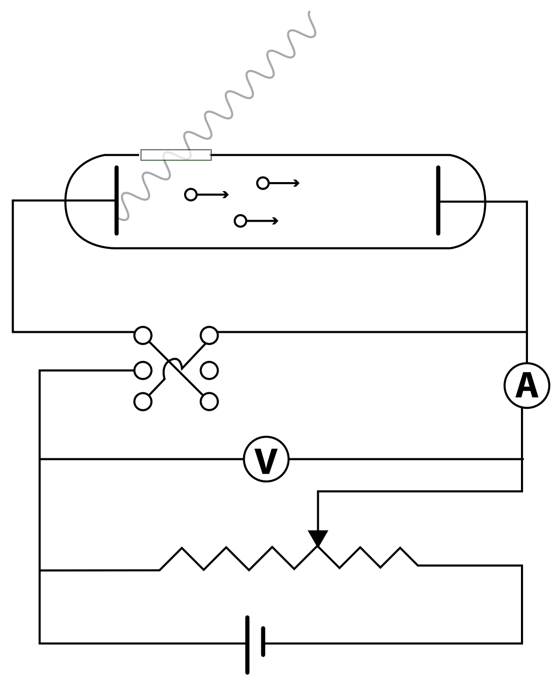
The following passage pertains to questions 11 - 15.

The photoelectric effect is the emission of electrons when electromagnetic radiation strikes a material. Electrons emitted in this manner can be called photoelectrons. In 1905, Einstein proposed an explanation of the photoelectric effect using a concept first put forward by Max Planck that light waves consist of tiny bundles or packets of energy known as photons or quanta.

The maximum kinetic energy of an ejected electron is given by

$$K_{mzx} = hf - \phi$$

The term ϕ is the work function which gives the minimum energy required to remove an electron from the surface of the metal.



The relation between current and applied voltage in the apparatus above illustrates the nature of the photoelectric effect. A light source illuminates a metal plate within a vacuum tube, and another plate electrode collects any emitted electrons. The potential between the two plates is varied and the current flowing in the external circuit between the two plates is measured.

If the frequency and the intensity of the incident radiation are fixed, the photoelectric current increases gradually with an increase in the positive potential on the collector electrode until all the photoelectrons emitted are collected. The photoelectric current attains a saturation value and does not increase further for any increase in the positive potential. The saturation current increases with the increase of the light intensity. It also increases with greater frequencies of incident light.

If we apply a negative potential to the collector plate Q with respect to the plate P and gradually increase it, the photoelectric current decreases, becoming zero at a certain negative potential. The negative potential on the collector at which the photoelectric current becomes zero is called the stopping potential.

11. If the device illuminating the metal is changed from a lamp producing mid UV light to a far UV lamp, the speed of emitted photoelectrons will

A. remain the same.
B. increase.
C. decrease.
D. become zero.

12. For a given frequency of incident radiation leading to production of photoelectrons in the apparatus depicted in the passage, the stopping potential

A. is determined by the minimum kinetic energy of the photoelecrons that are emitted.
B. decreases when a metal with lower threshold frequency is bombarded with the light.
C. increases with decreasing wavelength of incident light.
D. is independent of the intensity of the radiation.

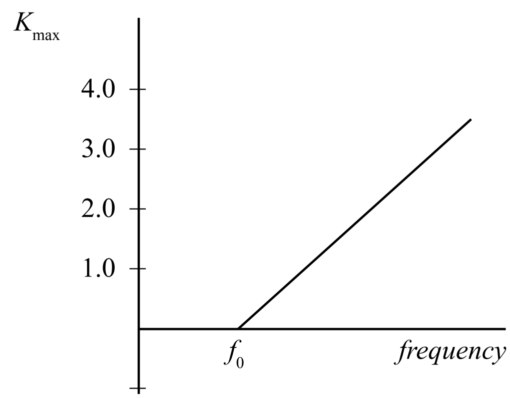
13. The graph below shows current measurements for a photoelectric effect trial with a constant intensity of varying frequencies of incident UV radiation on a 1.5 cm^2 copper plate. A positive potential was applied to the collector plate. Which is the correct way to compute the value of the work function for copper?

A. $(6.63 \times 10^{-34}\,\text{J·s})(1.1 \times 10^{15}\,\text{s}^{-1})$

B. $\dfrac{(6.63 \times 10^{-34}\,\text{J·s})(3 \times 10^{8}\,\text{m/s})}{(1.1 \times 10^{15}\,\text{s}^{-1})}$

C. $9.0 \times 10^{-19}\,\text{J} - (6.63 \times 10^{-34}\,\text{J·s})(1.1 \times 10^{15}\,\text{s}^{-1})$

D. $\dfrac{(6.63 \times 10^{-34}\,\text{J·s})(1.1 \times 10^{15}\,\text{s}^{-1})}{2\pi}$

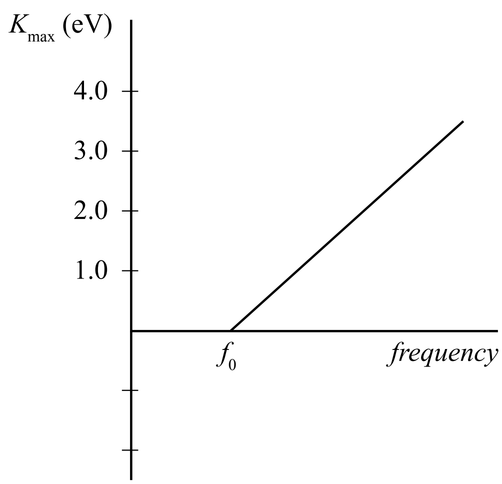


14. A trial was conducted using the apparatus depicted in the passage. A 145-nm light (*photon energy* = 8.55 eV) was shined on an unknown metal. The measured photocurrent dropped to zero at potential – 3.50 V. Determine the maximum kinetic energy possessed by the photoelectrons emitted from the metal surface.

A. 3.50 eV
B. 5.05 eV.
C. 8.55 eV.
D. 12.05 eV

15. The graph below represents a series of photoelectric effect trials employing a particular metal. Which of the following represents the work function of the metal?

A. 1.50 eV
B. 2.50 eV.
C. 3.00 eV.
D. 3.50 eV



Modern Physics

Answers and Explanations

1. C

To find the wavelength, divide the frequency into the wave speed.

$$\lambda = \frac{c}{f}$$

$$\lambda = \frac{3 \times 10^{8}\,\text{m/s}}{1.4 \times 10^{9}\,\text{s}^{-1}}$$

$$\lambda = 2.1 \times 10^{-1}\,\text{m}$$

Always let a problem be easy if it wants to be. Don't let the hand-waving with technical details convince you a problem is harder than it is.

2. B

Photon energy equals Planck's constant times the frequency.

Because our answer choices are very widely spaced, we can give ourselves plenty of allowance for mental math.

$$E = hf$$

$$E = \frac{hc}{\lambda}$$

$$E = \frac{(6.63 \times 10^{-34}\,\text{J·s})(3 \times 10^{8}\,\text{m/s})}{(5.05 \times 10^{-7}\,\text{m})}$$

$$E \sim \frac{(7 \times 10^{-34}\,\text{J·s})(3 \times 10^{8}\,\text{m/s})}{(5 \times 10^{-7}\,\text{m})}$$

$$E \sim 4 \times 10^{-19}\,\text{J}$$

3. D

The photoelectric effect exemplifies the particle (photon) nature of light. Diffraction exemplifies the wave nature of light.

4. B

Photon energy equals Planck's constant times the frequency.

$$E = hf$$

If source A emits light having half the frequency of source B, the energy of its photons must be half the energy of the photons of source B.

Power is the rate of energy expenditure. If the individual photons of source A have half the energy of those of source B, and source A is operating at half the power of source B, it directly follows that the two sources are emitting photons at the same rate.

5. B

First we need to determine the energy per photon. Photon energy equals Planck's constant times the frequency.

$$E = hf$$

$$E = \frac{hc}{\lambda}$$

$$E = \frac{(6.63 \times 10^{-34}\,\text{J·s})(3 \times 10^{8}\,\text{m/s})}{(5.98 \times 10^{-7}\,\text{m})}$$

$$E \sim \frac{(7 \times 10^{-34}\,\text{J·s})(3 \times 10^{8}\,\text{m/s})}{(6 \times 10^{-7}\,\text{m})}$$

$$E \sim 3.5 \times 10^{-19}\,\text{J}$$

We are given that the power of he laser is 100W. A watt is a joule per second. In other words the laser is consuming 100J per second. We previously determined how many joules per photon, so now we can determine how many photons per second.

$$\left(\frac{100\,\text{J}}{\text{s}}\right)\left(\frac{1\,\text{photon}}{3.5 \times 10^{-19}\,\text{J}}\right) \sim 3 \times 10^{20}\,\text{photon/s}$$

6. D

The Bohr radius (0.529 Å) is the most probable distance between the nucleus and the electron in a hydrogen atom in its ground state. It represents the most likely measured value, though values across a range are possible.

7. A

The photoelectric effect is the emission of electrons when light hits a material. Experiments by Einstein involving the photoelectric effect were instrumental in demonstrating the particle (photon) nature of light. Emission of conduction electrons from metals is especially salient, in many cases requiring photon energy of only a few electron-volts, corresponding to short-wavelength visible or ultraviolet light. The photoelectric effect will cause spacecraft exposed to sunlight to develop a positive charge. This can be a major problem, as other parts of the spacecraft are in shadow. The imbalance can discharge through delicate electrical components.

8. C

The transition energy equals the energy of the photon emitted. We are given the wavelength of the emitted photons in angstroms (Å = 10^{-10} m). Before we can compute the photon energy (Planck's constant times the frequency), we will need to convert the wavelength to meters (6564Å = 6.564×10^{-7}m).

$$E = hf$$

$$E = \frac{hc}{\lambda}$$

$$E = \frac{(6.63 \times 10^{-34}\,\text{J·s})(3 \times 10^{8}\,\text{m/s})}{(6.56 \times 10^{-7}\,\text{m})}$$

$$E \sim (1 \times 10^{-27})(3 \times 10^{8})\ \text{J}$$

$$E \sim 3 \times 10^{-19}\ \text{J}$$

9. C

The concept that matter behaves like a wave was proposed by Louis de Broglie. The de Broglie wavelength is the wavelength, λ, associated with a particle with mass. It is related to its momentum, $p = mv$, through the Planck constant, h:

$$\lambda = \frac{h}{mv}$$

The Davisson–Germer experiment confirmed the de Broglie hypothesis that matter has wave-like behavior. The initial intention of the Davisson and Germer experiment was to study the surface of nickel. They fired slow moving electrons at a crystalline nickel target. The reflected electron intensity was measured and was determined to have the same diffraction pattern as those predicted by Bragg for X-rays.

10. D

All matter exhibits wave-like behavior. For example, a beam of electrons can be diffracted just like a beam of light. The de Broglie wavelength is the wavelength, λ, associated with a particle with mass. It is related to its momentum, $p = mv$, through the Planck constant, h:

$$\lambda = \frac{h}{mv}$$

Of the choices presented, the α particle possesses the greatest mass, so if they all have the same speed, the α particle has the shortest de Broglie wavelength.

11. B

Far ultraviolet light is shorter wavelength (122nm - 200nm) than mid UV (200nm - 300nm). Shorter wavelength entails higher frequency, and higher frequency means greater photon energy.

$$E = hf$$

The greater the photon energy, the greater the maximum kinetic energy (and average kinetic energy) of emitted photoelectrons from the metal, so the greater the speed. The maximum kinetic energy equals incident photon energy minus the work function for the metal.

$$K_{mzx} = hf - \phi$$

12. D

If we apply a negative potential to the collector plate and gradually increase it, the photoelectric current decreases, becoming zero at a certain negative potential. This is called the stopping potential. For a given frequency of incident radiation, the stopping potential is determined by the maximum kinetic energy of the photoelectrons that are emitted. The maximum kinetic energy equals incident photon energy minus the work function for the metal.

$$K_{mzx} = hf - \phi$$

For a given frequency of incident radiation, the stopping potential is independent of its intensity.

13. A

In the photoelectric effect experiment electrons are dislodged only when the impinging light reaches or exceeds a threshold frequency. Below that threshold, no electrons are emitted from the material, regardless of the light intensity or the length of time of exposure to the light.

The maximum kinetic energy equals incident photon energy minus the work function for the metal.

$$K_{mzx} = hf - \phi$$

The threshold frequency, f_0, represents a photon energy just enough to overcome the work function, ϕ.

$$\phi = hf_0$$

Photon energy at the threshold frequency equals the work function. This is the minimum energy to liberate an electron from the metal.

14. A

The question stem gives us a stopping potential of -3.50V. At the stopping potential, the electric field between the plates is strong enough to bring even the most energetic photoelecrons to rest before striking the far plate. 3.50 V performs 3.50 eV of work on a single electron. If 3.50 V is the stopping potential, 3.50 eV is the maximum kinetic energy of the photoelectrons.

15. A

As described in the passage, the maximum kinetic energy of the photoelectrons ejected in a trial is given by

$$K_{mzx} = hf - \phi$$

The term ϕ is the work function, ie. the minimum energy required to remove an electron from the surface of the metal.

As can be seen in the equation above (and in the graph accompanying the question) the maximum kinetic energy varies linearly with the frequency of the incident radiation. This makes sense because the greater the frequency, the greater the photon energy, so the greater will be the energy possessed by the photoelectron after extraction from the metal.

A common motif in MCAT passages is to turn a question on the association of a linear equation presented in the passage with a graph, where the interpretation of the graph and equation in the light of slope intercept form can yield the values of certain physical quantities.

$$K_{mzx} = hf - \phi$$

$$y = mx + \mathrm{b}$$

On our graph the vertical intercept equals $-\phi$. Extension of the line shows that ϕ is approximately 1.5 eV.