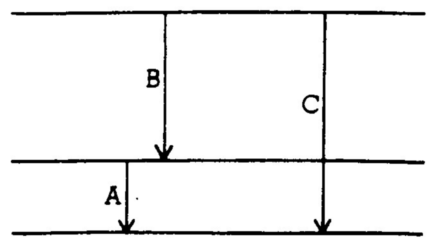
SECTION A – Quantum Physics and Atom Models

1975B5. The diagram above shows part of an energy-level diagram for a certain atom. The wavelength of the radiation associated with transition A is 600 nm (1 nm = 1 x 10^{-9} m) and that associated with transition B is 300 nm.



a. Determine the energy of a photon associated with transition A.
b. Determine the λ of the radiation associated with transition C
c. Describe qualitatively what will happen to an intense beam of white light (400 to 600 nm) that is sent through this gaseous element

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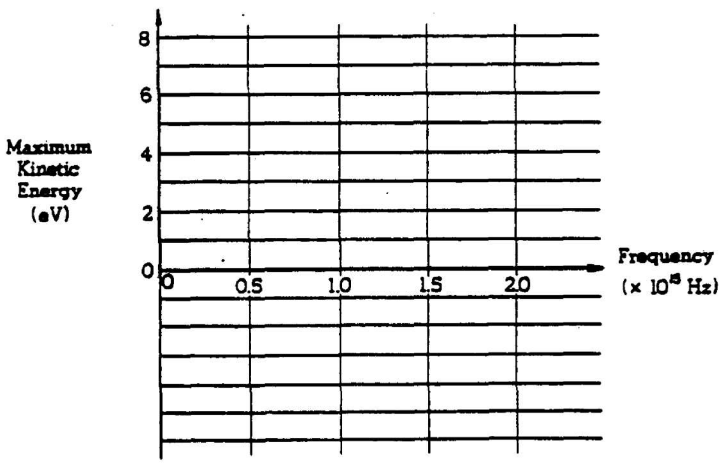
1980B3. In a photoelectric experiment, radiation of several different frequencies was made to shine on a metal surface and the maximum kinetic energy of the ejected electrons was measured at each frequency. Selected results of the experiment are presented in the table:

Frequency (Hz)	Maximum Kinetic Energy of Electrons (eV)
0.5×10^{15}	No electrons ejected
1.0×10^{15}	1.0
1.5×10^{15}	3.0
2.0×10^{15}	5.0

a. On the axes below, plot the data from this photoelectric experiment.



b. Determine the threshold frequency of the metal surface.
c. Determine the work function of the metal surface.
d. When light of frequency 2.0 x 10^{15} hertz strikes the metal surface, electrons of assorted speeds are ejected from the surface. What minimum retarding potential would be required to stop all of the electrons ejected from the surface by light of frequency 2.0 x 10^{15} hertz?
e. Investigation reveals that some electrons ejected from the metal surface move in circular paths. Suggest a reasonable explanation for this electron behavior.

1982B7. Select one of the following experiments:

I. The Michelson-Morley experiment
II. The Rutherford scattering experiment
III. The Compton scattering experiment
IV. The Davisson-Germer experiment

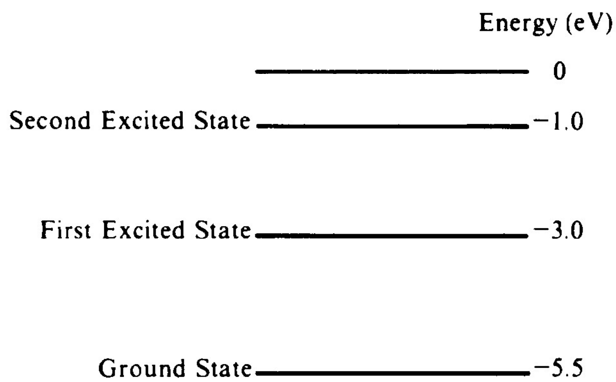
Clearly indicate the experiment you select and write an account of this experiment. Include in your account
a. a labeled diagram of the experimental setup
b. a discussion of the experimental observations
c. the important conclusions of the experiment

1983B6. An experiment is conducted to investigate the photoelectric effect. When light of frequency 1.0×10^{15} hertz is incident on a photocathode, electrons are emitted. Current due to these electrons can be cut off with a 1.0-volt retarding potential. Light of frequency 1.5×10^{15} hertz produces a photoelectric current that can be cut off with a 3.0-volt retarding potential.

a. Calculate an experimental value of Planck's constant based on these data.

b. Calculate the work function of the photocathode.

c. Will electrons be emitted from the photocathode when green light of wavelength 5.0×10^{-7} meter is incident on the photocathode? Justify your answer.



1985B6. An energy-level diagram for a hypothetical atom is shown above.

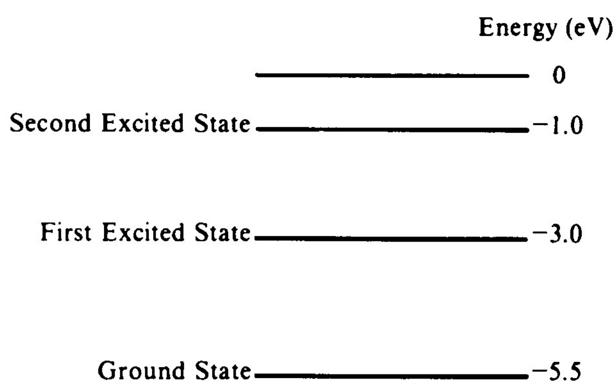
a. Determine the frequency of the lowest energy photon that could ionize the atom, initially in its ground state.

b. Assume the atom has been excited to the state at -1.0 electron volt.

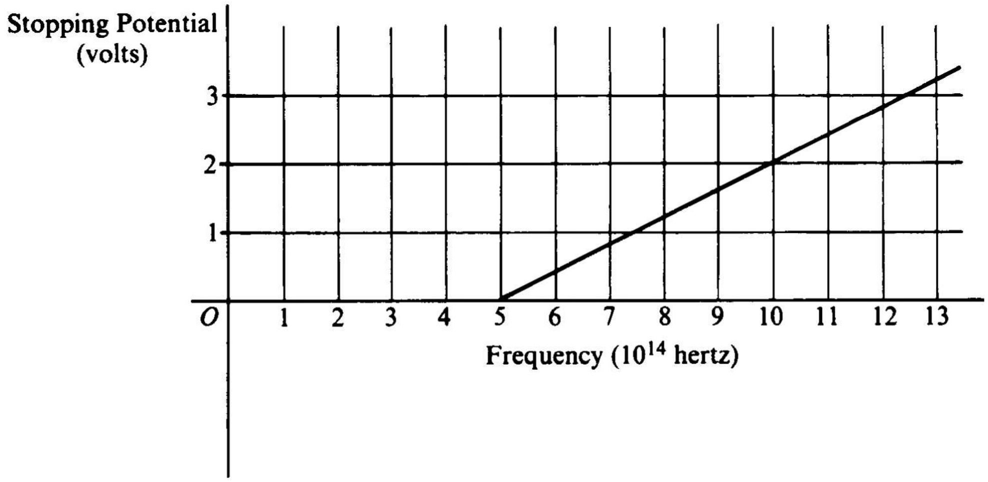
i. Determine the wavelength of the photon for each possible spontaneous transition.

ii. Which, if any, of these wavelengths are in the visible range?

c. Assume the atom is initially in the ground state. Show on the following diagram the possible transitions from the ground state when the atom is irradiated with electromagnetic radiation of wavelengths ranging continuously from 2.5×10^{-7} meter to 10.0×10^{-7} meter.

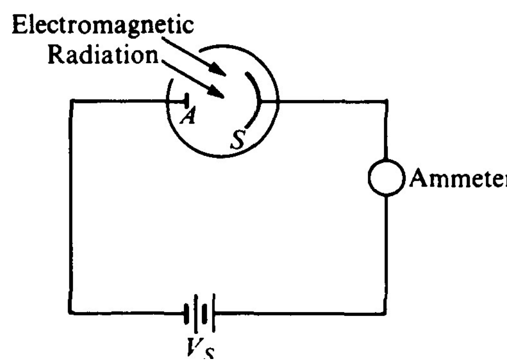


1987B6. In a photoelectric experiment, light is incident on a metal surface. Electrons are ejected from the surface, producing a current in a circuit. A reverse potential is applied in the circuit and adjusted until the current drops to zero. That potential at which the current drops to zero is called the stopping potential. The data obtained for a range of frequencies are graphed below.



a. For a frequency of light that has a stopping potential of 3 volts, what is the maximum kinetic energy of the ejected photoelectrons?
b. From the graph and the value of the electron charge, determine an experimental value for Planck's constant.
c. From the graph, determine the work function for the metal.
d. On the axes above, draw the graph for a different metal surface with a threshold frequency of 6.0 x 10^{14} hertz.

1988B6. Electromagnetic radiation is incident on the surface S of a material as shown. Photoelectrons are emitted from the surface S only for radiation of wavelength 500 nm or less. It is found that for a certain ultraviolet wavelength, which is unknown, a potential V_s of 3 volts is necessary to stop the photoelectrons from reaching the anode A, thus eliminating the photoelectric current.



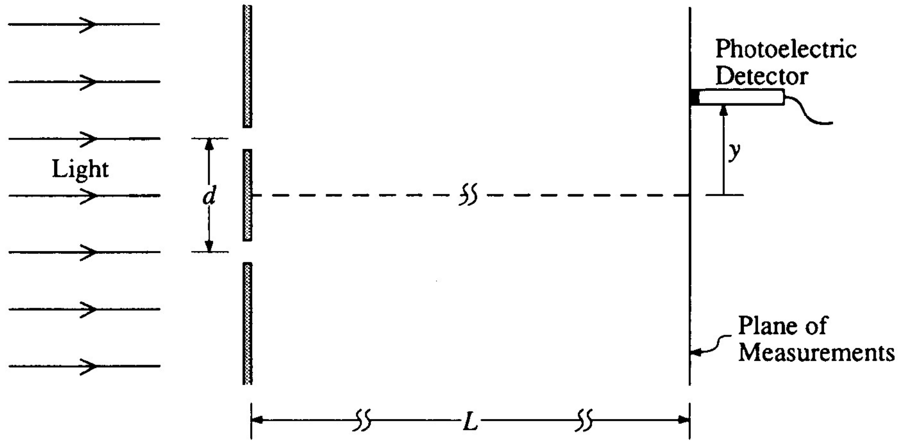
a. Determine the frequency of the 500 nm radiation.
b. Determine the work function for the material.
c. Determine the energy of the photons associated with the unknown wavelength.
d. Determine the unknown wavelength.

1990B5. In a television picture tube, electrons are accelerated from rest through a potential difference of 12,000 volts and move toward the screen of the tube. When the electrons strike the screen, x-ray photons are emitted. Determine:

a. the speed of an electron just before it strikes the screen
b. the number of electrons arriving at the screen per second if the flow of electrons in the tube is 0.01 coulomb per second

An x-ray of maximum energy is produced when an electron striking the screen gives up all of its kinetic energy. For such x-rays, determine:

c. the frequency
d. the wavelength
e. the photon momentum



1991B6. Light consisting of two wavelengths, $\lambda_a = 4.4 \times 10^{-7}$ meter and $\lambda_b = 5.5 \times 10^{-7}$ meter, is incident normally on a barrier with two slits separated by a distance d. The intensity distribution is measured along a plane that is a distance L = 0.85 meter from the slits as shown above. The movable detector contains a photoelectric cell whose position y is measured from the central maximum. The first-order maximum for the longer wavelength λ_b occurs at $y = 1.2 \times 10^{-2}$ meter.

a. Determine the slit separation d.

b. At what position Y_a does the first-order maximum occur for the shorter wavelength λ_a?

In a different experiment, light containing many wavelengths is incident on the slits. It is found that the photosensitive surface in the detector is insensitive to light with wavelengths longer than 6.0×10^{-7} m.

c. Determine the work function of the photosensitive surface.

d. Determine the maximum kinetic energy of electrons ejected from the photosensitive surface when exposed. to light of wavelength $\lambda = 4.4 \times 10^{-7}$ m.

1992B4. The ground-state energy of a hypothetical atom is at –10.0 eV. When these atoms, in the ground state, are illuminated with light, only the wavelengths of 207 nanometers and 146 nanometers are absorbed by the atoms. (1 nanometer = 10^{-9} meter).

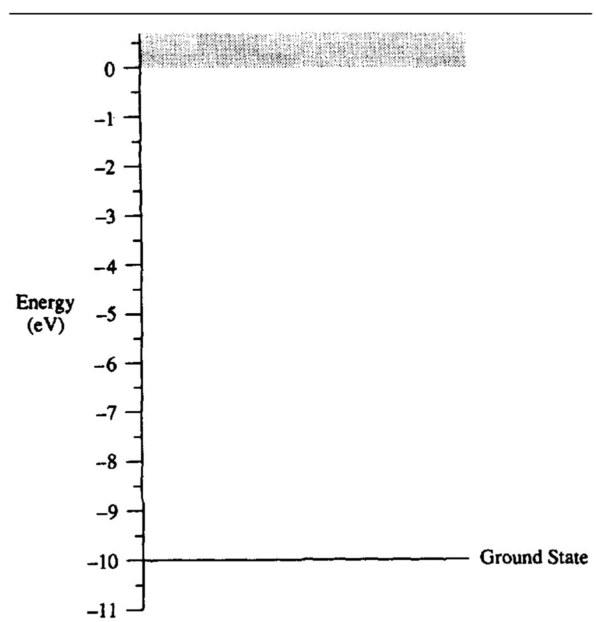
a. Calculate the energies of the photons of light of the two absorption-spectrum wavelengths.

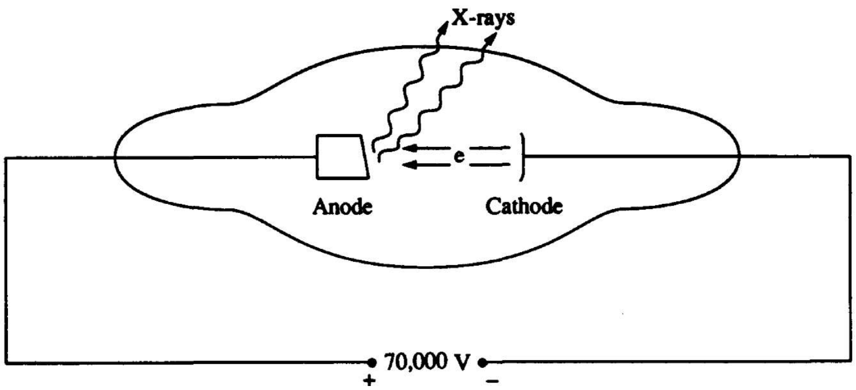
b. Complete the energy-level diagram shown for these atoms by showing all the excited energy states.

c. Show by arrows on the energy-level diagram all of the possible transitions that would produce emission spectrum lines.

d. What would be the wavelength of the emission line corresponding to the transition from the second excited state to the first excited state?

e. Would the emission line in (d) be visible? Briefly justify your answer

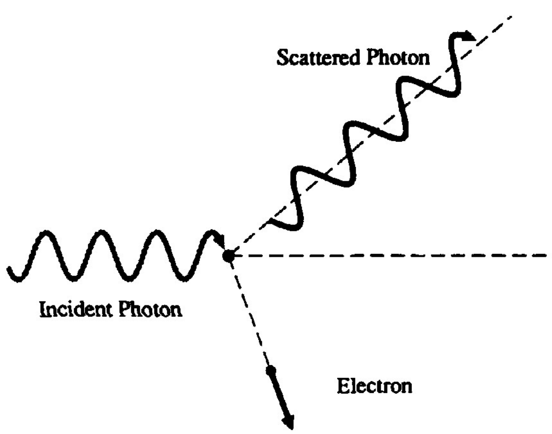




1993B6. In the x-ray tube shown above, a potential difference of 70,000 volts is applied across the two electrodes. Electrons emitted from the cathode are accelerated to the anode, where x-rays are produced.

a. Determine the maximum frequency of the x-rays produced by the tube.

b. Determine the maximum momentum of the x-ray photons produced by the tube.



An x-ray photon of the maximum energy produced by this tube leaves the tube and collides elastically with an electron at rest. As a result, the electron recoils and the x-ray is scattered, as shown above. The frequency of the scattered x-ray photon is 1.64×10^{19} hertz.

c. Determine the kinetic energy of the recoiled electron.

d. Determine the magnitude of the momentum of the recoiled electron.

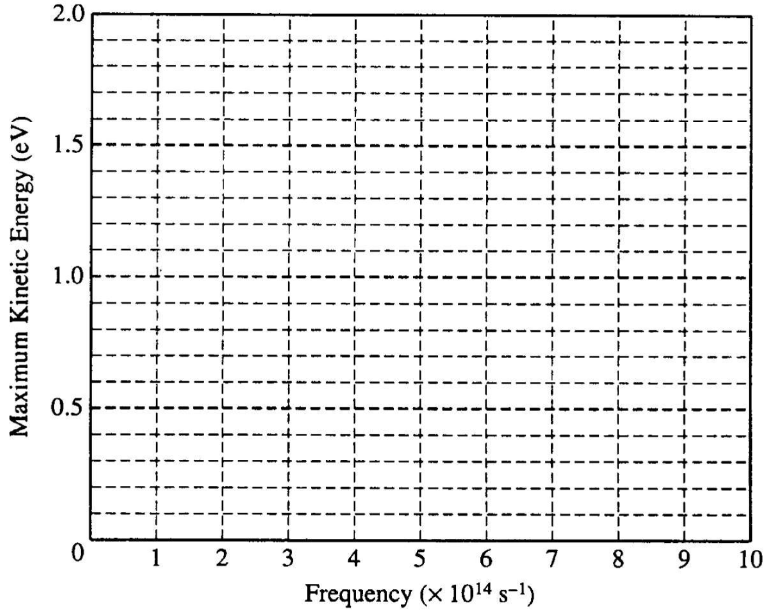
e. Determine the deBroglie wavelength of the electron

1994B3

A series of measurements were taken of the maximum kinetic energy of photoelectrons emitted from a metallic surface when light of various frequencies is incident on the surface.

a. The table below lists the measurements that were taken. On the axes below, plot the kinetic energy versus light frequency for the five data points given. Draw on the graph the line that is your estimate of the best straight-line fit to the data points

Light Frequency (10^{14} s^{-1})	Maximum Kinetic Energy (electron volts)
5.00	0.10
6.00	0.45
7.00	0.95
8.00	1.30
9.00	1.45



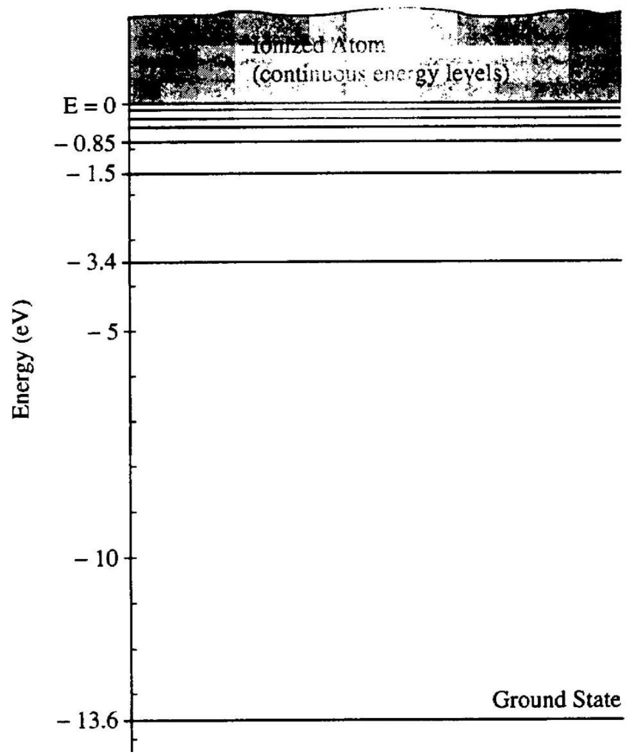
b. From this experiment, determine a value of Planck's constant h in units of electron volt-seconds. Briefly explain how you did this

1995B4. A free electron with negligible kinetic energy is captured by a stationary proton to form an excited state of the hydrogen atom. During this process a photon of energy E_a is emitted, followed shortly by another photon of energy 10.2 electron volts. No further photons are emitted. The ionization energy of hydrogen is 13.6 electron volts.

a. Determine the wavelength of the 10.2 eV photon.

b. Determine the following for the first photon emitted.
   i. The energy E_a of the photon
   ii. The frequency that corresponds to this energy

c. The following diagram shows some of the energy levels of the hydrogen atom, including those that are involved in the processes described above. Draw arrows on the diagram showing only the transitions involved in these processes.

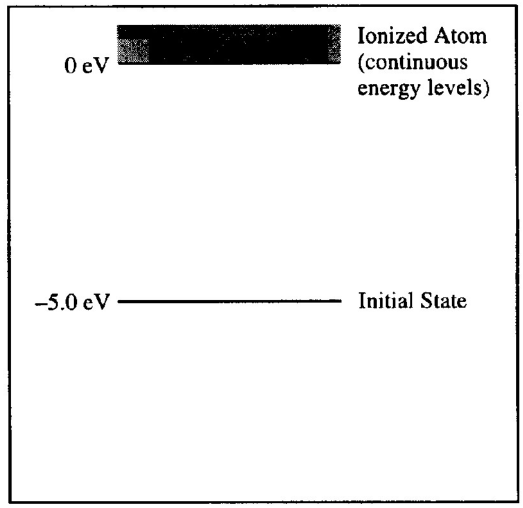


d. The atom is in its ground state when a 15 eV photon interacts with it. All the photon's energy is transferred to the electron, freeing it from the atom. Determine the following.
   i. The kinetic energy of the ejected electron
   ii. The de Broglie wavelength of the electron

1997B6
Select one of the experiments below, and for the experiment you pick answer parts (a) and (b) that follow.

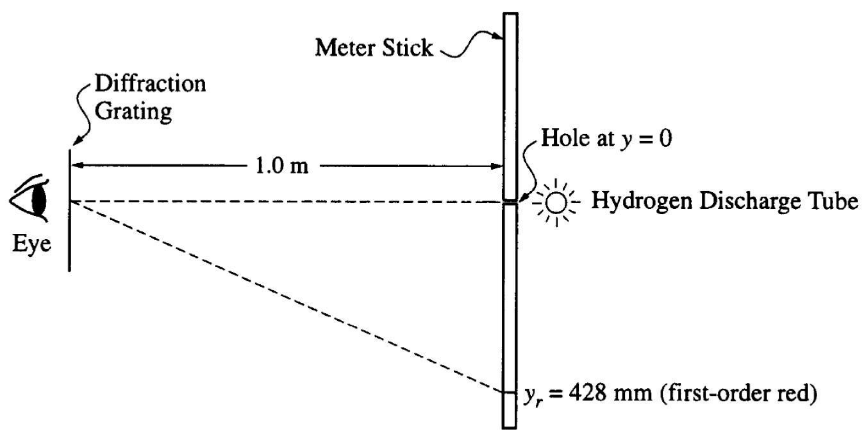
i. Rutherford scattering experiment ii. Michelson-Morley experiment iii. Photoelectric-effect experiment

a. Draw a simple diagram representing the experimental setup and label the important components.
b. Briefly state the key observation(s) in this experiment and indicate what can be concluded from them.



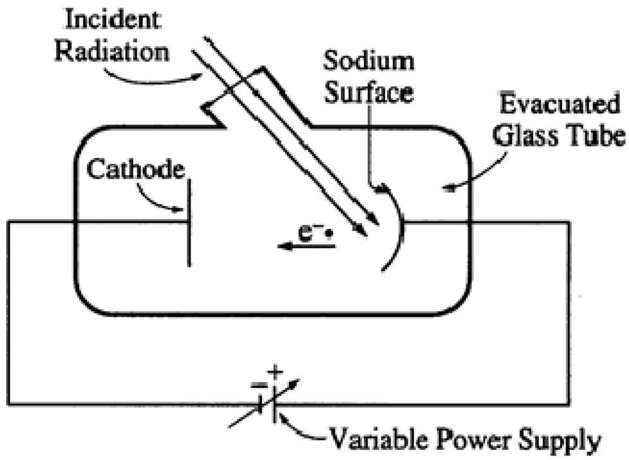
A monatomic gas is illuminated with visible light of wavelength 400 nm. The gas is observed to absorb some of the light and subsequently to emit visible light at both 400 nm and 600 nm.

c. In the box, complete an energy level diagram that would be consistent with these observations. Indicate and label the observed absorption and emissions.
d. If the initial state of the atoms has energy –5.0 eV, what is the energy of the state to which the atoms were excited by the 400 nm light?
e. At which other wavelength(s) outside the visible range do these atoms emit radiation after they are excited by the 400 nm light?



1998B7. A transmission diffraction grating with 600 lines/mm is used to study the line spectrum of the light produced by a hydrogen discharge tube with the setup shown above. The grating is 1.0 m from the source (a hole at the center of the meter stick). An observer sees the first-order red line at a distance y_r = 428 mm from the hole.

a. Calculate the wavelength of the red line in the hydrogen spectrum.
b. According to the Bohr model, the energy levels of the hydrogen atom are given by $E_n = -13.6\text{ eV}/n^2$, where n is an integer labeling the levels. The red line is a transition to a final level with n = 2. Use the Bohr model to determine the value of n for the initial level of the transition.
c. Qualitatively describe how the location of the first-order red line would change if a diffraction grating with 800 lines/mm were used instead of one with 600 lines/mm.



2000B5. A sodium photoelectric surface with work function 2.3 eV is illuminated by electromagnetic radiation and emits electrons. The electrons travel toward a negatively charged cathode and complete the circuit shown above. The potential difference supplied by the power supply is increased, and when it reaches 4.5 V, no electrons reach the cathode.

a. For the electrons emitted from the sodium surface, calculate the following.
   i. The maximum kinetic energy
   ii. The speed at this maximum kinetic energy
b. Calculate the wavelength of the radiation that is incident on the sodium surface.
c. Calculate the minimum frequency of light that will cause photoemission from this sodium surface.

2002B7. A photon of wavelength 2.0 x 10^{-11} m strikes a free electron of mass m_e that is initially at rest, as shown above left. After the collision, the photon is shifted in wavelength by an amount $\Delta\lambda = 2h/m_e c$, and reversed in direction, as shown above right.

(a) Determine the energy in joules of the incident photon.
(b) Determine the magnitude of the momentum of the incident photon.
(c) Indicate below whether the photon wavelength is increased or decreased by the interaction.
    ___Increased   _______Decreased
    Explain your reasoning.
(d) Determine the magnitude of the momentum acquired by the electron.

B2002B7. An experimenter determines that when a beam of mono–energetic electrons bombards a sample of a pure gas, atoms of the gas are excited if the kinetic energy of each electron in the beam is 3.70 eV or greater.

(a) Determine the deBroglie wavelength of 3.70 eV electrons.

(b) Once the gas is excited by 3.70 eV electrons, it emits monochromatic light. Determine the wavelength of this light.

Experiments reveal that two additional wavelengths are emitted if the beam energy is raised to at least 4.90 eV.
(c) Construct an energy-level diagram consistent with this information and determine the energies of the photons associated with those two additional wavelengths.

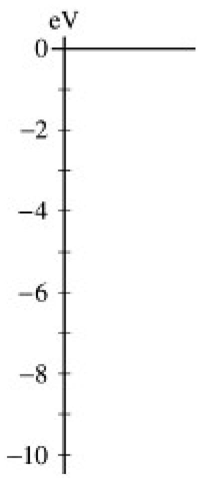
B2003B7. An experiment is performed on a sample of atoms known to have a ground state of −5.0 eV. The gas is illuminated with “white light” (400 – 700 nm). A spectrometer capable of analyzing radiation in this range is used to measure the radiation. The sample is observed to absorb light at only 400 nm. After the “white light” is turned off, the sample is observed to emit visible radiation of 400 nm and 600 nm.

(a) In the space below, determine the values of the energy levels and on the following scale sketch an energy level diagram showing the energy values in eV’s and the relative positions of:

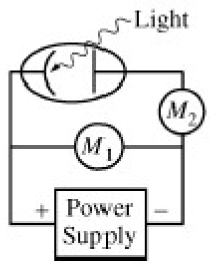
i. the ground state

ii. the energy level to which the system was first excited

iii. one other energy level that the experiment suggests may exist



(b) What is the wavelength of any other radiation, if any, that might have been emitted in the experiment? Why was it not observed?



2004B6. A student performs a photoelectric effect experiment in which light of various frequencies is incident on a photosensitive metal plate. This plate, a second metal plate, and a power supply are connected in a circuit, which also contains two meters, M_1 and M_2, as shown above.

The student shines light of a specific wavelength λ onto the plate. The voltage on the power supply is then adjusted until there is no more current in the circuit, and this voltage is recorded as the stopping potential V_s .

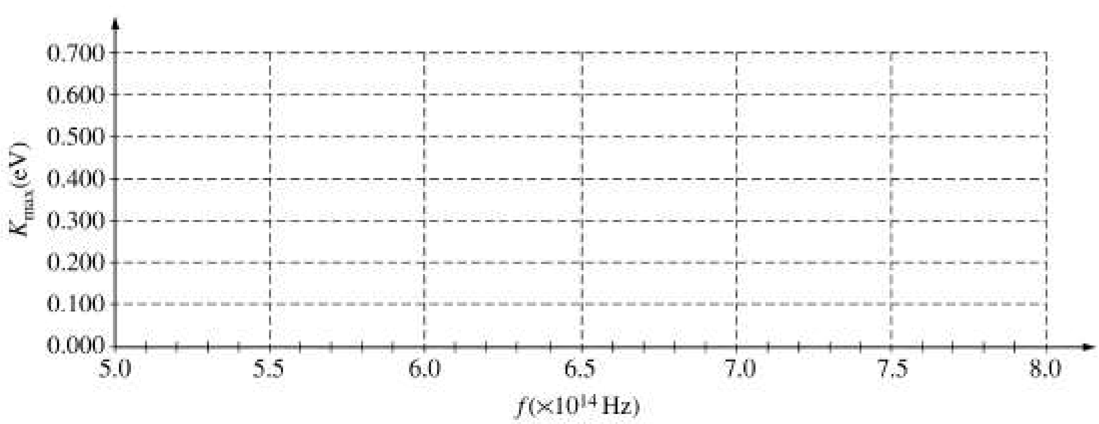
The student then repeats the experiment several more times with different wavelengths of light. The data, along with other values calculated from it, are recorded in the table below.

λ (m)	4.00×10^{-7}	4.25×10^{-7}	4.50×10^{-7}	4.75×10^{-7}
V_S (volts)	0.65	0.45	0.30	0.15
f (Hz)	7.50×10^{14}	7.06×10^{14}	6.67×10^{14}	6.32×10^{14}
K_{max} (eV)	0.65	0.45	0.30	0.15

(a) Indicate which meter is used as an ammeter and which meter is used as a voltmeter by checking the appropriate spaces below.

	M_1	M_2
Ammeter	_____	_____
Voltmeter	_____	_____

(b) Use the data above to plot a graph of *Kmax* versus *f* on the axes below, and sketch a best-fit line through the data.

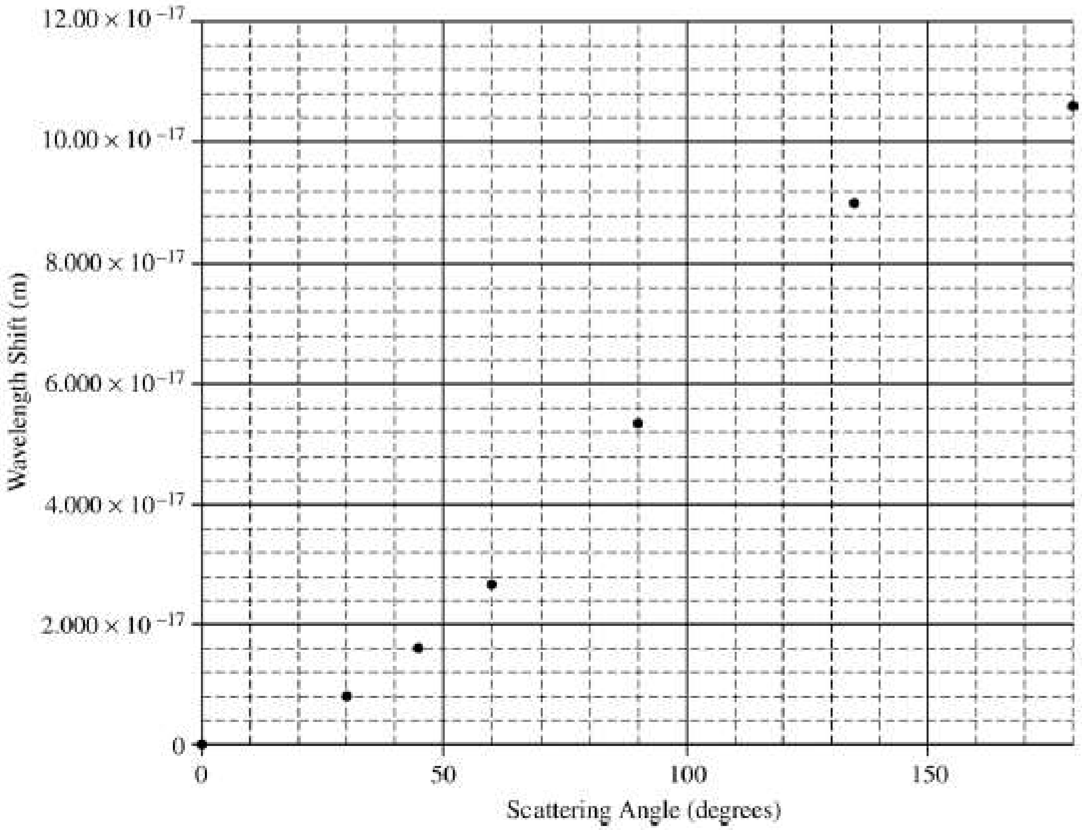


(c) Use the best-fit line you sketched in part (b) to calculate an experimental value for Planck's constant.

(d) If the student had used a different metal with a larger work function, how would the graph you sketched in part (b) be different? Explain your reasoning.

B2004B6.

An incident gamma ray photon of wavelength 1.400 x 10^{-14} m is scattered off a stationary nucleus. The shift in wavelength of the photon is measured for various scattering angles, and the results are plotted on the graph shown below.



(a) On the graph, sketch a best-fit curve to the data.

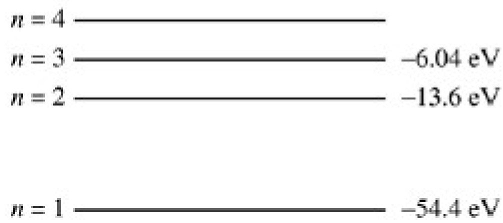
In one of the trials, the photon is scattered at an angle of 120° with its original direction.

(b) Calculate the wavelength of this photon after it is scattered off the nucleus.

(c) Calculate the momentum of this scattered photon.

(d) Calculate the energy that this scattering event imparts to the recoiling nucleus.

2005B7



The diagram above shows the lowest four discrete energy levels of an atom. An electron in the $n = 4$ state makes a transition to the $n = 2$ state, emitting a photon of wavelength 121.9 nm.
(a) Calculate the energy level of the $n = 4$ state.
(b) Calculate the momentum of the photon.

The photon is then incident on a silver surface in a photoelectric experiment, and the surface emits an electron with maximum possible kinetic energy. The work function of silver is 4.7 eV.
(c) Calculate the kinetic energy, in eV, of the emitted electron.
(d) Determine the stopping potential for the emitted electron.

B2005B7. A monochromatic source emits a 2.5 mW beam of light of wavelength 450 nm.

(a) Calculate the energy of a photon in the beam.
(b) Calculate the number of photons emitted by the source in 5 minutes.

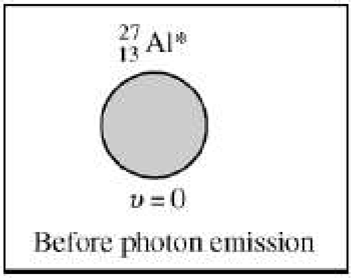
The beam is incident on the surface of a metal in a photoelectric-effect experiment. The stopping potential for the emitted electron is measured to be 0.86 V.

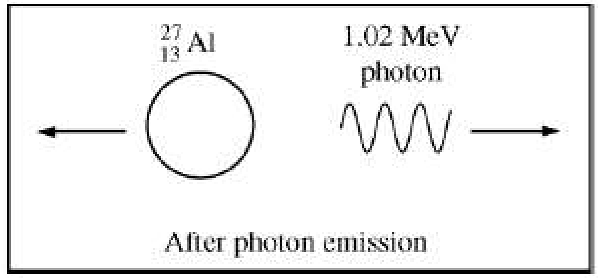
(c) Calculate the maximum speed of the emitted electrons.
(d) Calculate the de Broglie wavelength of the most energetic electrons.

2006B6. A photon with a wavelength of 1.5×10^{-8} m is emitted from an ultraviolet source into a vacuum.
(a) Calculate the energy of the photon.
(b) Calculate the de Broglie wavelength of an electron with kinetic energy equal to the energy of the photon.
(c) Describe an experiment that illustrates the wave properties of this electron.

2008B7. In an electron microscope, a tungsten cathode with work function 4.5 eV is heated to release electrons that are then initially at rest just outside the cathode. The electrons are accelerated by a potential difference to create a beam of electrons with a de Broglie wavelength of 0.038 nm.
(a) Calculate the momentum of an electron in the beam, in kg-m/s.
(b) Calculate the kinetic energy of an electron in the beam, in joules.
(c) Calculate the accelerating voltage.
(d) Suppose that light, instead of heat, is used to release the electrons from the cathode. What minimum frequency of light is needed to accomplish this?

B2008B7.



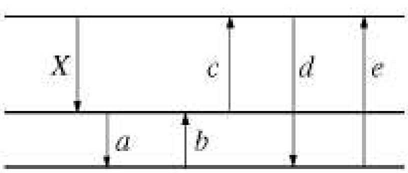


Following a nuclear reaction, a nucleus of aluminum is at rest in an excited state represented by $^{27}_{13}Al^*$, as shown above left. The excited nucleus returns to the ground state $^{27}_{13}Al$ by emitting a gamma ray photon of energy 1.02 MeV, as shown above right. The aluminum nucleus in the ground state has a mass of 4.48×10^{-26} kg.

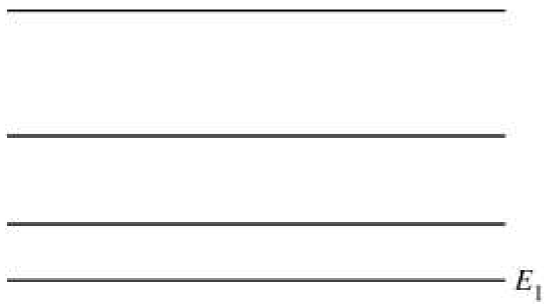
(a) Calculate the wavelength of the emitted photon in meters.
(b) Calculate the momentum of the emitted photon in kg-m/s.
(c) Calculate the speed of the recoiling nucleus in m/s.
(d) Calculate the kinetic energy of the recoiling nucleus in joules.

2009B7. A photon of wavelength 250 nm ejects an electron from a metal. The ejected electron has a de Broglie wavelength of 0.85 nm.

(a) Calculate the kinetic energy of the electron.
(b) Assuming that the kinetic energy found in (a) is the maximum kinetic energy that it could have, calculate the work function of the metal.
(c) The incident photon was created when an atom underwent an electronic transition. On the energy level diagram of the atom below, the transition labeled *X* corresponds to a photon wavelength of 400 nm. Indicate which transition could be the source of the original 250 nm photon by circling the correct letter. Justify your answer.



B2009B6.



The electron energy levels above are for an electron confined to a certain very small one-dimensional region of space. The energy E_n of the levels, where $n = 1, 2, 3, \ldots$, is given by $E_n = n^2 E_1$. Express all algebraic answers in terms of E_1 and fundamental constants.

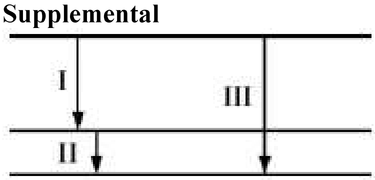
(a) On the diagram above, label the three excited energy levels with the values for their energies in terms of E_1, the energy of the ground state.

(b) Calculate the smallest frequency of light that can be absorbed by an electron in this system when it is in the ground state, $n = 1$.

(c) If an electron is raised into the second excited state, draw on the diagram all the possible transitions that the electron can make in returning to the ground state.

(d) Calculate the wavelength of the highest energy photon that can be emitted in the transitions in part (c).

Supplemental



The diagram above shows a portion of the energy-level diagram for a particular atom. When the atom undergoes transition I, the wavelength of the emitted radiation is 400 nm, and when it undergoes transition II, the wavelength is 700 nm.

(a) Calculate the wavelength of the emitted radiation when the atom undergoes transition III.

A photon emitted during transition III is then incident on a metal surface of work function 2.1 eV.

(b) Calculate the maximum kinetic energy of the electron ejected from the metal by the photon.

(c) Calculate the de Broglie wavelength of the ejected electron.

SECTION B – Nuclear Physics

1989B6. A lithium nucleus, while at rest, decays into a helium nucleus of rest mass 6.6483 x 10^{-27} kilogram and a proton of rest mass 1.6726 x 10^{-27} kilogram, as shown by the following reaction.

$$^{5}_{3}Li \rightarrow ^{4}_{2}He + ^{1}_{1}H$$

In this reaction, momentum and total energy are conserved. After the decay, the proton moves with a speed of 1.95 x 10^{7} m/s.

a. Determine the kinetic energy of the proton.
b. Determine the speed of the helium nucleus.
c. Determine the kinetic energy of the helium nucleus.
d. Determine the mass that is transformed into kinetic energy in this decay.
e. Determine the rest mass of the lithium nucleus.

1996B5. An unstable nucleus that is initially at rest decays into a nucleus of fermium-252 containing 100 protons and 152 neutrons and an alpha particle that has a kinetic energy of 8.42 MeV. The atomic masses of helium-4 and fermium-252 are 4.00260 u and 252.08249 u, respectively.

a. What is the atomic number of the original unstable nucleus?
b. What is the velocity of the alpha particle?
c. Where does the kinetic energy of the alpha particle come from? Explain briefly.
d. Assuming all of the energy released in the reaction is in the form of kinetic energy of the alpha particle, determine the exact mass of the original unstable nucleus, to an accuracy of 3 thousandths of a decimal.
e. Suppose that the fermium-252 nucleus could undergo a decay in which a β^{-} particle was produced. How would this affect the atomic number of the nucleus? Explain briefly.

1999B4. A Geiger counter is used to measure the decay of a radioactive sample of bismuth 212 over a period of time.

a. The bismuth isotope decays into thallium by emitting an alpha particle according to the following equation:

$$^{212}_{83}Bi \rightarrow Tl + \alpha$$

Determine the atomic number Z and the mass number A of the thallium nuclei produced and enter your answers in the spaces provided below.

Z= ____________________ A= ____________________

b. The mass of the alpha particle is 6.64 x 10^{-27} kg. Its measured kinetic energy is 6.09 MeV and its speed is much less than the speed of light.
   i. Determine the momentum of the alpha particle.
   ii. Determine the kinetic energy of the recoiling thallium nucleus.
c. Determine the total energy released during the decay of 1 mole of bismuth 212.

2001B7. Consider the following nuclear fusion reaction that uses deuterium as fuel. $3(^{2}_{1}\text{H}) \rightarrow ^{4}_{2}\text{He} + ^{1}_{1}\text{H} + ^{1}_{0}\text{n}$

a. Determine the mass defect of a single reaction, given the following information.

$$^{2}_{1}H = 2.0141u \qquad ^{4}_{2}He = 4.0026u \qquad ^{1}_{1}H = 1.0078u \qquad ^{1}_{0}n = 1.0087u$$

b. Determine the energy in joules released during a single fusion reaction.
c. The United States requires about 10^{20} J per year to meet its energy needs. How many deuterium atoms would be necessary to provide this magnitude of energy?
d. What mass of deuterium, in kg, is needed to provide this energy per year

B2006B6. An electron of mass m is initially moving with a constant speed v , where $v << c$. Express all algebraic answers in terms of the given quantities and fundamental constants.
(a) Determine the kinetic energy of the electron.
(b) Determine the de Broglie wavelength of the electron.

The electron encounters a particle with the same mass and opposite charge (a positron) moving with the same speed in the opposite direction. The two particles undergo a head-on collision, which results in the disappearance of both particles and the production of two photons of the same energy.
(c) Determine the energy of each photon.
(d) Determine the wavelength of each photon.
(e) Explain why there must be two photons produced instead of just one.

B2007B7. In the vicinity of a heavy nucleus, a high-energy photon can be converted into two particles: an electron and a positron. A positron has the same mass as the electron and equal but opposite charge. This process is called pair production.
(a) Calculate the rest energy of an electron, in eV.
(b) Determine the minimum energy, in eV, that a photon must have to give rise to pair production.
(c) Calculate the wavelength corresponding to the photon energy found in part (b).
(d) Calculate the momentum of the photon.

2007B7. It is possible for an electron and a positron to orbit around their stationary center of mass until they annihilate each other, creating two photons of equal energy moving in opposite directions. A positron is a particle that has the same mass as an electron and equal but opposite charge. The amount of kinetic energy of the electron–positron pair before annihilation is negligible compared to the energy of the photons created.
(a) Calculate, in eV, the rest energy of a positron.
(b) Determine, in eV, the energy each emitted photon must have.
(c) Calculate the wavelength of each created photon.
(d) Calculate the magnitude of the momentum of each photon.
(e) Determine the total momentum of the two-photon system.