10 Figure 38-23 shows an electron moving (a) opposite an elec-**10** Figure 38-23 shows an electron moving (a) opposite an electron some vertic field, (c) in the same direction as an electric field, (c) in the same direction as a magnetic field, and (d) perpendicular to a electron the **10** Figure 38-23 shows an electron moving (a) opposite an elec-
tric field, (b) in the same direction as an electric field, (c) in the three region
same direction as a magnetic field, and (d) perpendicular to a
magnetic **10** Figure 38-23 shows an electron moving (a) opposite an electric field, (b) in the same direction as an algertic field, (c) in the three same direction as a magnetic field, and (d) perpendicular to a electron the elect 10 Figure 38-23 shows an electron moving (a) opposite an elec-
tric field, (b) in the same direction as an electric field, (c) in the the three
same direction as a magnetic field, and (d) perpendicular to a electron
magne

12 An electron and a proton have the same kinetic energy. Which has the greater de Broglie wavelength?

13 The following nonrelativistic particles all have the same ki-

14 Figure 38-24 shows an electron moving through several re-

PROBLEMS 1181
V have been set up. Rank
Proclis movelenath of the **PROBLEMS** 1181
gions where uniform electric potentials V have been set up. Rank
the three regions according to the de Broglie wavelength of the
electron there, greatest first.
15. The table gives relative values for three the three regions according to the de Broglie wavelength of the **EXECT:**
 E

15 The table gives relative values for three situations for the bar-**PROBLEMS** 1181
gions where uniform electric potentials V have been set up. Rank
the three regions according to the de Broglie wavelength of the
electron there, greatest first.
15 The table gives relative values for three tions according to the probability of the electron tunneling **Exercise 18 Technomic Service Service** through the barrier, greatest first.

gives the transmission coefficient T for electron tunneling through a polengths of the electrons are identical (a) E 5E L

(b) E 17E L/2

(c) E 2E 2L
 16 For three experiments, Fig. 38-25 L

gives the transmission coefficient T

for electron tunneling through a po-

for electron tunneling through a po-

thrickness L. The de Brog difference in the physical setups is the barrier heights U_b . Rank the three experiments according to U_b , greatest first. in the three experiments. The only

T

Figure 38-25 Question 16.

Problems

Module 38-1 The Photon, the Quantum of Light

- be absorbed by a sheet of photographic film and thus recorded on The detector faces an isotropic source, 3.00 m from the source. If **Photon absorption**

Tutoring problem available (at instructor's discretion) in *WileyPLUS* and WebAssign

SSM Worked-out solution available in Student Solutions Manual

WWW Worked-out solutional information available in **Contains 1.1 Exceeds** 1.1 The Photon available (at instructor's discretion) in *WileyPLUS* and W

SSM Worked-out solution available in Student Solutions Manual

Contains 2.1 The Photon, the Quantum of Light

Module 38-1 T **Example 1115**
 Example 1115
 Example 1115
 Example 1115
 Example 1115
 Example 1116
 Example 11 Monted-out solution available in Student Solutions Manual
 Example 1116
 Example 116
 Example 116
 Example ate an AgBr molecule in the film. (a) What is the greatest \bullet The beam emerging from a 1.5 W argon laser (λ = 515 nm) wavelength of light that can be recorded by the film? (b) In what has a diameter d of 3.0 mm. The **Example 19**
 Example 10
 Example 10 1 Monochromatic light (that is, light of a single wavelength) is to

be absorbed by a sheet of photographic film and thus recorded on

the film. Photon absorption will occur if the photon energy equals

or exceeds 0.6 eV, be absorbed by a sheet of photographic film and thus recorded on The detector faces an isotropic soil or exceeds 0.6 eV, the smallest amount of energy needed to dissocionally the detector absorbs photons at the film. (a) the film. Photon absorption will occur if the photon energy equals

are an AgBr molecule in the film. (a) What is the greatest

are are acced to dissoci-

wavelength of light that can be recorded by the film? (b) In what

- $\sqrt{2}$ How fast must an electron move to have a kinetic energy strikes a totally absorbing screen, where it forms a circular
- assume that the Sun's entire emission at the rate of 3.9×10^{26} W is
screen in the central disk of the diffraction pattern?
- A detector in the beam's path totally absorbs the beam.At what rate per unit area does the detector absorb photons? wavelength of methods and the excluded by the limit (b) in what has a diameter d

region of the electromagnetic spectrum is this wavelength located?
 •2 How fast must an electromomove to have a kinetic energy strikes a
- the orange light emitted by a source containing krypton-86 atoms. What is the photon energy of that light?
- sodium lamp at a wavelength of 589 nm?

••7 A light detector (your eye) has an area of 2.00×10^{-6} m² and absorb Branch is at the incident light,
 Figure 38-25 Question 16.

Interactive solution is at **http://www.wiley.com/college/halliday**
 absorb S0% of the incident light, which is at wavelength 500 nm.

The detector fa Figure 30-23 Question 10.

igno

Worked-out solution is at

Interactive solution is at
 Interactive solution is at
 Interactive solution is at
 Interactive solution is at
 Interactive source, 3.00 m from the sourc the detector absorbs photons at the rate of exactly 4.000 s^{-1} , at and

am.

e. If

, at

(m)

em what power does the emitter emit light? **Figure 1.5**
 Example 1.5 The beam emerged and the beam emerged and the beam emerged and absorbs 80% of the incident light, which is at wavelength 500 nm.

The detector faces an isotropic source, 3.00 m from the source

Follow EV and Solution is at **http://www.wiley.com/college/halliday**
 example of 1.0 metacles subsets and a lens of 2.00 × 10⁻⁶ m² and
 example by a lens subsets and is follow a
 exame is follow absorbs 80% of Worked-out solution is at

Interactive solution is at

sofphysics.com
 and

sofphysics.com
 and

absorbs 80% of the incident light, which is at wavelength 500 nm.

The detector faces an isotropic source, 3.00 m from t **The matrix solution is at**
 Interactive solution is at
 I absorbs 80% of the incident light, whi diffraction pattern whose central disk has a radius R given by **••7** A light detector (your eye) has an area of 2.00×10^{-6} m² and absorbs 80% of the incident light, which is at wavelength 500 nm. The detector faces an isotropic source, 3.00 m from the source. If the detector ab **••7** A light detector (your eye) has an area of 2.00×10^{-6} m² and
absorbs 80% of the incident light, which is at wavelength 500 nm.
The detector faces an isotropic source, 3.00 m from the source. If
the detector ab A right detector (your eye) has an area of 2.00 × 10 ° m- and
absorbs 80% of the incident light, which is at wavelength 500 nm.
The detector faces an isotropic source, 3.00 m from the source. If
the detector absorbs photo The detector faces an isotropic source, 3.00 m from the source. If
the detector absorbs photons at the rate of exactly 4.000 s⁻¹, at
what power does the emitter emit light?
••8 The beam emerging from a 1.5 W argon las the detector absorbs photons at the rate of exactly 4.000 s⁻¹, at
what power does the emitter emit light?
 ••8 The beam emerging from a 1.5 W argon laser (λ = 515 nm)
has a diameter *d* of 3.0 mm. The beam is focus **•8** The beam emerging from a 1.5 W argon laser ($\lambda = 515$ nm)
has a diameter d of 3.0 mm. The beam is focused by a lens system
with an effective focal length f_L of 2.5 mm. The focused beam
strikes a totally absorbing s **Example 1** in the beam emerging itom a 1.5 w argon raset $(A - 315)$ innit has a diameter *d* of 3.0 mm. The beam is focused by a lens system with an effective focal length f_L of 2.5 mm. The focused beam strikes a totall and diameter *a* of 3.0 mm. The beam is focused by a fens system
with an effective focal length f_L of 2.5 mm. The focused beam
strikes a totally absorbing screen, where it forms a circular
diffraction pattern whose cent region of the electromagnetic spectrum is this wavelength located? with an effective focal length f_L of 2.5 mm. The focused beam •3 At what rate does the Sun emit photons? For simplicity, $1.22 f_L \lambda/d$. It can be shown that 84% of the incident energy ends up

lamp? (b) At what distance from the lamp will a totally absorbing screen absorb photons at the rate of 1.00 photon/ $\text{cm}^2 \cdot \text{s}$? (c) What diffraction pattern whose central disk has a radius R given by

1.22 $f_L \lambda/d$. It can be shown that 84% of the incident energy ends up

within this central disk. At what rate are photons absorbed by the

screen in the centr 1.22 $f_L \lambda/d$. It can be shown that 84% of the incident energy ends up within this central disk. At what rate are photons absorbed by the screen in the central disk. At what rate are photons absorbed by the screen in the ce reads up
ends up
the sorbing
of by the
sorbing
c) What
a small
ar cells
i's light
(a) At
aat rate

••10 A satellite in Earth orbit maintains a panel of solar cells what rate does solar energy arrive at the panel? (b) At what rate What is the photon energy for yellow light from a highway rays. The intensity of the light at the panel is 1.39 kW/m² (a) At

1182 CHAPTER 38 PHOTONS AND MATTER WAVES
are solar photons absorbed by the panel? Assume that the solar ejected electrons then move in circular
andiation is measubsensation with a worrelangle of 550 cm and the funiform ma are solar photons absorbed by the panel? Assume that the solar **1182** CHAPTER 38 PHOTONS AND MATTER WAVES
are solar photons absorbed by the panel? Assume that the solar ejected electrons then move in circul
radiation is monochromatic, with a wavelength of 550 nm, and of uniform magne 1182 CHAPTER 38 PHOTONS AND MATTER WAVES
are solar photons absorbed by the panel? Assume that the solar ejected electrons then move in circ
radiation is monochromatic, with a wavelength of 550 nm, and of uniform magnetic absorbed by the panel? 1182 CHAPTER 38 PHOTONS AND MATTER WAVES

are solar photons absorbed by the panel? Assume that the solar

radiation is monochromatic, with a wavelength of 550 nm, and

that all the solar radiation striking the panel is ab 1182 CHAPTER 38 PHOTONS AND MATTER WAVES

are solar photons absorbed by the panel? Assume that the solar ejected electron

radiation is monochromatic, with a wavelength of 550 nm, and of uniform m

that all the solar radi 1182 CHAPTER 38 PHOTONS AND MATTER WAVES
are solar photons absorbed by the panel? Assume that the solar ejected electrons
radiation is monochromatic, with a wavelength of 550 nm, and of uniform magt
that all the solar rad

••11 SSM WWW An ultraviolet lamp emits light of wavelength ••22 The waveler tons at the greater rate and (b) what is that greater rate?

are solar photons absorbed by the panel? Assume that the solar
radiation is monochromatic, with a wavelength of 550 nm, and
that all the solar radiation striking the panel is absorbed.
trons, the product *Br*
absorbed by are solar photons absorbed by the panel? Assume that the solar ejected electrons then move in circ

radiation is monochromatic, with a wavelength of 550 nm, and of uniform magnetic field \vec{B} . For

that all the solar r are some broods absorbed by the panel in the solar corresponding radiation is monochromatic, with a wavelength of 550 mm, and of uniform magnetic f
that all the solar radiation striking the panel is absorbed. It considers retina? **aboorbed by the panel?** in removised absorbed by the panel?
 aboorbed by the panel? aboon a in the rate of 400 W. An infrared lamp emits light of wave-silver is 2

length 700 nm, also at the rate of 400 W. (a) Whic **(a)** Table 10 W and the rate of 400 W. An infrared lamp emits light of wavelength $\frac{1}{2}$ The waveler 400 mm at the rate of 400 W. An infrared lamp emits light of wavelers iver is 325 nm. Flength 700 nm, also at the ra **Example 19 and 19 From any of the Facture 10** Food W. Farmaria camp emits right of length 700 nm, also at the rate of 400 W. (a) Which lamp emitons at the greater rate and (b) what is that greater rate?
 CHACC CHACC CHACC CHACC C

••13 A special kind of lightbulb emits monochromatic light of ••24 In a photoelectric experiment using a sodium surface, you which whereas system and a special control which is a second. What is the eye's retina at a rate as low as 100 photons per second. What energy is subseted by the what is it is the corresponding rate at which energy is abs

•• 14 **co** A light detector has an absorbing area of 2.00×10^{-6} m² and absorbs 50% of the incident light, detector faces an isotropic source, **13** A special kind of lightbulb emits monochromatic light of
 13 A special kind of lightbulb emits monochromatic light of

wavelength 630 nm. Electrical energy is supplied to it at the rate of

60 W, and the bulb is 93 E emitted by the source versus time **13** A special kind of lightbulb emits monochromatic lightar wavelength 630 nm. Electrical energy is supplied to it at the rat 60 W, and the bulb is 93% efficient at converting that energy light energy. How many photons a wavelength 630 nm. Electrical energy is supplied to it at 60 W, and the bulb is 93% efficient at converting that light energy. How many photons are emitted by the bull lifetime of 730 h?
 •14 \bullet A light detector has a absorbed by the detector? •14 **C** A light detector has an ab-

sorbing area of 2.00×10^{-6} m² and

absorbs 50% of the incident light,

which is at wavelength 600 nm. The

detector faces an isotropic source,

12.0 m from the source versus time sorbing area of 2.00 × 10⁻⁶ m² and
absorbs 50% of the incident light, W_0 and absorbs 50% of the incident light, W_0 detector faces an isotropic source,
the site and absorbs and the incident wavelength is changed absorbs 50% of the incident light, E_s the incident wavelength 600 nm. The

detector faces an isotropic source,

Lentited by the source The energy

Lentited by the source versus time
 t is given in Fig. 38-26 ($E_s = 7.2$

Figure 38-26 Problem 14.

Module 38-2 The Photoelectric Effect

of the incident light? 1.2.0 m from the source. The energy
 t is given in Fig. 38-26 (*E_s* = 7.2 nJ,
 t_s = 2.0 s). At what rate are photons of the same of the same of the same of the material's and the detector?
 Module 38-2 The Photoe $t_s = 2.0 \text{ s}$). At what rate are photons of the diaborbed by the detector?
 Figure 38-26 Problem 14. can run the sensit coated with platinum
 Module 38-2 The Photoelectric Effect ($\Phi = 5.32 \text{ eV}$). Find the speed of **Module 38-2 The Photoelectric Effect** (composited and the work function of sodium surface, causing photoelectric the energision. The stopping potential for the ejected electrons is 5.0 V, and the work function of sodium V.15 SSM Light strikes a sodium surface, causing photoelectric

frequency of the incident radiation is 3.0×10^{15} Hz.

of the fastest electrons ejected from a tungsten surface when light

 $\frac{18}{18}$ You wish to pick an element for a photocell that will operate
via the photoelectric effect with visible light. Which of the follow-
via the photoelectric effect with visible light. Which of the follow-
 $\frac{180$ **Via the photoelect in the solution** surface, causing photoelectric

and the work function of sodium is 2.2 eV. What is the wavelength

and the work function of sodium is 2.2 eV. What is the wavelength

of the incident li emission. Ine stopping potential for the ejected electrons is 5.0 v,
and the work function of sodium is 2.2 eV. What is the wavelength
of the incident light?
 416 Find the maximum kinetic energy of electrons ejected fro and the work tunction of sodium is 2.2 eV. What is the wavelength
 Computer (4.5 eV) and the maximum kinetic energy of electrons ejected from a
 Computer Computer Computer
 Computer (4.5 eV), tungsten is 4.50 eV. Ca **16** Find the maximum kinetic energy of electrons eject
 416 Find the maximum kinetic energy of electrons eject

certain material if the material's work function is 2.3 eV

frequency of the incident radiation is 3.0 × 1 ••19 Find the maximum knetic energy of electrons ejected from a

frequency of the incident radiation is 3.0 × 10¹⁵ Hz.

frequency of the incident radiation is 3.0 × 10¹⁵ Hz.
 ••17 The work function of tungsten is 4. Irequency of the incident radiation is 3.0×10^{15} Hz.
 (a) In MeV of the fastest electrons ejected from a tungsten surface when light ciated with a ph

whose photon energy is 5.80 eV shines on the surface.
 (a) whose photon energy is 5.80 eV shines on the surface.
 Cause of the Surface energy? What are used in a brotoclectric effect with visible light. Which of the follow-
 $\frac{\sqrt{29}}{29}$ What (a) frequence suitable (work func

the stopping potential for electrons ejected from the metal when maximum speed of the ejected electrons?

••20 Suppose the *fractional efficiency* of a cesium surface (with work function 1.80 eV) is 1.0×10^{-16} ; that is, on average one elec-18 You wish to pick an element for a photocell that will operate

via the photoelectric effect with visible light. Which of the follow-

ing are suitable (work functions are in parentheses): tantalum (4.2

every that (a) ing are suitable (work functions are in parentheses): tantalum (4.2 mentum magnitude (iieV), tungsten (4.5 eV), aluminum (4.2 eV), barium (2.5 eV), wavelength 35.0 pm?
 a30 What is the max
 a30 What is the max
 a30 the ejected electrons took part in the charge flow? **••30** What is th
 ••19 (a) If the work function for a certain metal is 1.8 eV, what is
 ••19 (a) If the work function for a certain metal is 1.8 eV, what is

the stopping potential for electrons ejected from the meta

that all the solar radiation striking the panel is absorbed. trons, the product Br is equal to 1.88×10^{-4} T m. Find (a) the ejected electrons then move in circular paths of radius r in a region ES

ejected electrons then move in circular paths of radius r in a region

of uniform magnetic field \vec{B} . For the fastest of the ejected elec-

trons, the product Br is equal to 1.88×10^{-4} T·m. Find (a) the

maxim Example is equal to the move in circular paths of radius r in a region
of uniform magnetic field \vec{B} . For the fastest of the ejected elec-
trons, the product Br is equal to 1.88×10^{-4} T · m. Find (a) the
maximum k maximum kinetic energy of those electrons and (b) the work done in removing them from the gold atoms. ejected electrons then move in circular paths of radius *r* in a region
of uniform magnetic field \vec{B} . For the fastest of the ejected elec-
trons, the product *Br* is equal to 1.88 × 10⁻⁴ T·m. Find (a) the
maximum k ES

ejected electrons then move in circular paths of ranger

of uniform magnetic field \vec{B} . For the fastest of

trons, the product Br is equal to 1.88×10^{-4} T

maximum kinetic energy of those electrons and (

in ejected electrons then move in circular paths of radius r in a region
of uniform magnetic field \vec{B} . For the fastest of the ejected elec-
trons, the product Br is equal to 1.88×10^{-4} T·m. Find (a) the
maximum kin ejected electrons then move in circular paths of radius r in a region
of uniform magnetic field \vec{B} . For the fastest of the ejected elec-
trons, the product Br is equal to 1.88×10^{-4} T·m. Find (a) the
maximum kin of uniform magnetic field \vec{B} . For the fastest of the ejected elec-

•• 22 The wavelength associated with the cutoff frequency for ejected from a silver surface by ultraviolet light of wavelength

energy of (a) the fastest and (b) the slowest ejected electrons? (c) What is the stopping potential for this situation? (d) What is the cutoff wavelength for aluminum? maximum kinetic energy of those electrons and (b) the work done
in removing them from the gold atoms.
 ••22 The wavelength associated with the cutoff frequency for
silver is 325 nm. Find the maximum kinetic energy of el **Example 1.1** and the stopping a stopping a stopping and the stopping and silver is 325 nm. Find the maximum kinetic energy of electrons ejected from a silver surface by ultraviolet light of wavelength 254 nm .
 CALC a stopping associated with the cutoff frequency for silver is 325 nm. Find the maximum kinetic energy of electrons ejected from a silver surface by ultraviolet light of wavelength 254 nm.
 a a a a a a a a silver is 325 nm. Find the maximum kinetic energy of electrons
ejected from a silver surface by ultraviolet light of wavelength
254 nm.
••23 SSM Light of wavelength 200 nm shines on an aluminum
surface; 4.20 eV is requi ejected from a silver surface by ultraviolet light of wavelength

254 nm.
 •23 SSM Light of wavelength 200 nm shines on an aluminum

surface; 4.20 eV is required to eject an electron. What is the kinetic

energy of (a) 254 nm.
 ••23 SSM Light of wavelength 200 nm shines on an aluminum

surface; 4.20 eV is required to eject an electron. What is the kinetic

energy of (a) the fastest and (b) the slowest ejected electrons? (c)

What is t •• 23 SSM Light of wavelength 200 nm shines on an aluminum

function Φ for sodium, and (c) the cutoff wavelength λ_0 for sodium.

••23 SSM Light of wavelength 200 nm shines on an aluminum surface; 4.20 eV is required to eject an electron. What is the kinetic energy of (a) the fastest and (b) the slowest ejected electrons? (c) What is the stopping surface; 4.20 eV is required to eject an electron. What is the kinetic
energy of (a) the fastest and (b) the slowest ejected electrons? (c)
What is the stopping potential for this situation? (d) What is the
cutoff wavelen energy of (a) the fastest and (b) the slowest ejected electrons? (c)
What is the stopping potential for this situation? (d) What is the
cutoff wavelength for aluminum?
 ••24 In a photoelectric experiment using a sodium work function for the surface?

•• 26 An orbiting satellite can become charged by the photoelectric effect when sunlight ejects electrons from its outer surface. $t(s)$ Satellites must be designed to minimize such charging because it as stopping potential of 0.820 V for a wavelength of 400 nm. From
these data find (a) a value for the Planck constant, (b) the work
function Φ for sodium, and (c) the cutoff wavelength λ_0 for sodium.
••25 The sto these data find (a) a value for the Planck constant, (b) the work
function Φ for sodium, and (c) the cutoff wavelength λ_0 for sodium.
••25 \bullet The stopping potential for electrons emitted from a sur-
face illumi function Φ for sodium, and (c) the cutoff wavelength λ_0 for sodium.
 •25 \bullet The stopping potential for electrons emitted from a sur-

face illuminated by light of wavelength 491 nm is 0.710 V. When

the inciden that can eject an electron from the platinum. tential is 1.43 V. (a) What is this new wavelength? (b) What is the
work function for the surface?
••26 An orbiting satellite can become charged by the photoelec-
tric effect when sunlight ejects electrons from its oute work function for the surface?
 ••26 An orbiting satellite can become charged by the photoelectric effect when sunlight ejects electrons from its outer surface.

Satellites must be designed to minimize such charging bec **at 30.0°** An orbiting satellite can become charged by the photoelectric effect when sunlight ejects electrons from its outer surface.
Satellites must be designed to minimize such charging because it can ruin the sensitiv Satellites must be designed to minimize such charging because it
can ruin the sensitive microelectronics. Suppose a satellite is
coated with platinum, a metal with a very large work function
($\Phi = 5.32$ eV). Find the long

Module 38-3 Photons, Momentum, Compton Scattering, Light Interference

 $\frac{1}{16}$ Find the maximum kinetic energy of electrons ejected from a containing free electrons (a) Find the wavelength of light scattered ing angle of 120°. **V-27** SSM Light of wavelength 2.40 pm is directed onto a target

ciated with a photon having an energy equal to the electron rest energy? What are the (b) wavelength and (c) frequency of the corresponding radiation? **Module 38-3 Photons, Momentum, Compton Scattering,**
 Light Interference
 COMPTE 1997 Example 12.40 pm is directed onto a target

containing free electrons (a) Find the wavelength of light scattered

at 30.0° from t **Light Interference**
 Example 12.40 pm is directed onto a tacontaining free electrons (a) Find the wavelength of light scatt

at 30.0° from the incident direction. (b) Do the same for a scating angle of 120°.
 P28 (a)

mentum magnitude (in keV/c) are associated with x rays having

•• 30 What is the maximum wavelength shift for a Compton collision between a photon and a free proton?

•• 31 What percentage increase in wavelength leads to a 75% loss of photon energy in a photon–free electron collision?

would be the current of electrons ejected from such a surface if it ding change in photon energy, (c) the kinetic energy of the recoil-**••32** (a) in MeV/c, what is the magnitude of the momentum associated with a photon having an energy equal to the electron rest energy? What are the (b) wavelength and (c) frequency of the corresponding radiation?
 •• direction of an x axis onto a target containing loosely bound elecenergy? what are the (b) wavelength and (c) rrequency of the corresponding radiation?
 (29 What (a) frequency, (b) photon energy, and (c) photon mo-

mentum magnitude (in keV/c) are associated with x rays having
 (30 responding radiation?
 429 What (a) frequency, (b) photon energy, and (c) photon mo-

mentum magnitude (in keV/c) are associated with x rays having
 430 What is the maximum wavelength shift for a Compton colli-
 430 129 What (a) frequency, (b) photon energy, and (c) photon mo-
mentum magnitude (in keV/c) are associated with x rays having
wavelength 35.0 pm?
130 What is the maximum wavelength shift for a Compton colli-
sion betwee mentum magnitude (in keV/c) are associated with x rays having
wavelength 35.0 pm?
••30 What is the maximum wavelength shift for a Compton colli-
sion between a photon and a free *proton*?
••31 What percentage increase the x axis and the electron's direction of motion? **••31** What percentage increase in wavelength leads to a 75% loss
 ••31 What percentage increase in wavelength leads to a 75% loss

of photon energy in a photon–free electron collision?

••32 X rays of wavelength 0.0100

gold foil and eject tightly bound electrons from the gold atoms. The collision like that in Fig. 38-5 for $\phi = 90^{\circ}$ and for radiation in •• 33 Calculate the percentage change in photon energy during a

(a) the microwave range, with $\lambda = 3.0$ cm; (b) the visible range, tion is almost imm with $\lambda = 500$ nm; (c) the x-ray range, with $\lambda = 25$ pm; and (d) the cules, which produ gamma-ray range, with a gamma photon energy of (a) the microwave range, with $\lambda = 3.0$ cm; (b) the visible range, tion is almost immediately a with $\lambda = 500$ nm; (c) the x-ray range, with $\lambda = 25$ pm; and (d) the cules, which produces another gamma-ray range, with a g (a) the microwave range, with $\lambda = 3.0$ cm; (b) the visible range, tion is almost immediately absorbe with $\lambda = 500$ nm; (c) the x-ray range, with $\lambda = 25$ pm; and (d) the cules, which produces another idea gamma-ray rang (a) the microwave range, with $\lambda = 3.0$ cm; (b) the visible range, tion is almost im with $\lambda = 500$ nm; (c) the x-ray range, with $\lambda = 25$ pm; and (d) the cules, which proclusions about the feasibility of detecting the co Compton shift in these various regions of the electromagnetic (a) the microwave range, with $\lambda = 3.0$ cm; (b) the visible range, tion is almost in with $\lambda = 500$ nm; (c) the x-ray range, with $\lambda = 25$ pm; and (d) the cules, which programma-ray range, with a gamma photon energy of 1. photon–electron encounter? (a) the microwave range, with $\lambda = 3.0$ cm; (b) the visible range, tion is almost immediately a

with $\lambda = 500$ nm; (c) the x-ray range, with $\lambda = 25$ pm; and (d) the cules, which produces anothe

gamma-ray range, with a (a) the microwave range, with $\lambda = 3.0$ cm; (b) the visible range, tion is almost in with $\lambda = 500$ nm; (c) the x-ray range, with $\lambda = 25$ pm; and (d) the cules, which programma-ray range, with a gamma photon energy of 1. (a) the microwave range, with $\lambda = 3.0$ cm; (b) the visible range, tion is almost in with $\lambda = 500$ nm; (c) the x-ray range, with $\lambda = 25$ pm; and (d) the cules, which programma-ray range, with a gamma photon energy of 1. with $\lambda = 500 \text{ nm}$; (c) the x-ray range, with $\lambda = 25 \text{ pm}$; and (d) the cules, which proparma-ray range, with a gamma photon energy of 1.0 MeV.

(e) What are your conclusions about the feasibility of detecting the which (e) What are your conclusions about the feasibility of det
Compton shift in these various regions of the electro-
spectrum, judging solely by the criterion of energy loss in
photon-electron encounter?
••34 $\bullet \bullet$ A phot

kinetic energy?

wave with a wavelength equal to the Compton wavelength of

and a aluminum target and are scattered in various directions by
an aluminum target and are scattered in various directions by
and the same of which was gone in the magnetic in a wavelength game. loosely bound electrons there. (a) What is the wavelength of the incoosely bound electrons there. (a) what is the wavelength of the line of 1.00 nm at that wavelength, from a surface area of 4.00 cm², and cident gamma rays? (b) What is the wavelength of gamma rays free electron. The photon scatters at 90.0° from its initial direction;
its initial wavelength is 3.00×10^{-12} m. What is the electron's
kinetic energy?
••35 Calculate the Compton wavelength for (a) an electron and
(ergy of the rays scattered in this direction? ••35 Calculate the Compton wavelength for (a) an electron and

(b) a proton. What is the photon energy for an electromagnetic

wave with a wavelength equal to the Compton wavelength of

••36 Gamma rays of photon energy 0. (b) a proton. What is the photon energy for an electromagnetic

wave with a wavelength equal to the Compton wavelength of
 Compton wavelength of
 Compton wavelength of
 Compton and (c) the electron and (d) the proto an aluminum target and are scattered in various directions by

loosely bound electrons there. (a) What is the wavelength of the in-

cident gamma rays? (b) What is the wavelength of gamma rays

considered at 90.0° to the

•• 37 Consider a collision between an x-ray photon of initial enthe energy of the backscattered photon? (b) What is the kinetic $\frac{46}{46}$ Calculate the de Broglie wavelength of (a) a 1.00 keV election?
tron, (b) a 1.00 keV photon, and (c) a 1.00 keV neutron. energy of the electron? **••39** Through what angle must a 200 keV photon be scattered by
 ••37 Consider a collision between an x-ray photon of initial en-
 ••37 Consider a collision between an x-ray photon of initial en-

tered backward and t

••38 Show that when a photon of energy E is scattered from a electron is given by

$$
K_{\max} = \frac{E^2}{E + mc^2/2}.
$$

••40 GO What is the maximum kinetic energy of electrons knocked out of a thin copper foil by Compton scattering of an incident beam **EXAMPLE SMPLE SMPLE SURVER CONCOUNTED** and through a potential difference of 300 V. (a) What is the momentum **EXECUTE:** The backscattered photon? (b) What is the kinetic

energy of the electron?
 ••38 Show that when a photon of energy E is scattered from a

free electron at rest, the maximum kinetic energy of the recoiling

el

••43 Show that when a photon of energy E is scattered from a
 ••38 Show that when a photon of energy of the recoiling and through a potentie electron is given by
 $K_{\text{max}} = \frac{E^2}{E + mc^2/2}$

••39 Through what angle mus ••38 Show that when a photon of energy *E* is scattered from a

free electron at rest, the maximum kinetic energy of the recoiling at del hrough

electron is given by
 $K_{\text{max}} = \frac{E^2}{E + mc^2/2}$.

••39 Through what angle m Light of wavelength $\lambda = 500$ nm scattering from a free, initially sta-
include the angles increase the mass include the state of state and the state of the state of the state electron so that the photon loses 10% of its tionary electron if the scattering is at 90° to the direction of the **43** Through what angle must dimension (*r*
 439 Through what angle must a 200 keV photon be scattered by
 448 The smallest dimension (*r*
 448 Wavelength of its electrons Chat at are electrons of that the photon l tering for photon energy 50.0 keV (x-ray range)? **Example 19** What is the maximum kinetic energy of electrons knocked
out of a thin copper foil by Compton scattering of an incident beam
of 17.5 keV x rays? Assume the work function is negligible.
Compton shift $\Delta\lambda$,

•42 The Sun is approximately an ideal blackbody radiator with a has radius $R = 5.0$ fm, what is the ratio R/λ ?
surface temperature of 5800 K. (a) Find the wavelength at which its ••51 SSM The wavelength of the yellow sp spectral radiancy is maximum and (b) identify the type of electroof 17.5 keV x rays? Assume the work function is negligible.
 Compton shift $\Delta \lambda$, do Compton shift $\Delta \lambda$, do the change ΔE in photon energy for
 Compton sift $\Delta \lambda \lambda$, and (c) the change ΔE in photon energy fo **•41** What are (a) the Compton shift $\Delta\lambda$, (b) the fractional
Compton shift $\Delta\lambda/\lambda$, and (c) the change ΔE in photon energy for
light of wavelength $\lambda = 590$ nm scattering from a free, initially sta-
Broglie wavelen (c) As we shall discuss in Chapter 44 , the diliverse is approximately
an ideal blackbody radiator with radiation emitted when atoms were distinct that the province that the constitution is 4.00 \times light of wavelength $\lambda = 590$ nm scattering from a free, initially sta-
tionary electron if the scattering is at 90° to the direction of the
incident beam? What are (d) $\Delta\lambda$, (e) $\Delta\lambda/\lambda$, and (f) ΔE for 90° scat-
te tionary electron if the scattering is at 90° to the direction of the

incident beam? What are (d) $\Delta\lambda$, (e) $\Delta\lambda/\lambda$, and (f) ΔE for 90° scat-
 Ele between momentum microsity of the microsity of the energy is so la corresponding temperature of the universe? **Fraction** intering tor photon energy 50.0 KeV (x-ray range)?
 Module 38-4 The Birth of Quantum Physics

surface temperature of 5800 K. (a) Find the wavelength at which its

spectral radiancy is maximum and (b) identify **42** The Sun is approximately an ideal blackbody radiator with a surface temperature of 5800 K. (a) Find the wavelength at which its spectral radiancy is maximum and (b) identify the type of electromagnetic wave correspon surface temperature of solution (a) identify the type of electromagnetic wave corresponding to that wavelength. (See Fig. 33-1.) that wavelength as its dependent radiancy of that radiation emitted when atoms an ideal blac

Example and the interval blackbody radiator with a surface temperature of \bullet **53** What is the wavelength of (a) a photon with energy 1.00 eV, about 1 0 \times 1.07 K (c) Find the unventure of the thermal results (b) an diation is maximum and (b) identify the type of electromagnetic 1.00 GeV , and (d) an electron with energy 1.00 GeV?
wave corresponding to that wavelength. (See Fig. 33-1.) This radia-
 \bullet 54 An electron and a photon e

PROBLEMS 1183 tion is almost immediately absorbed by the surrounding air mole-**EXECUTE STATES CONTIFY CONTINUM SET ALLO SET ALLO SET ALLO SET ALLO SET ALLO SET ANOTHER SUBSED AND SUMPTURE SUBSED ANOTES ANOTES ANOTHER SUPER SUPE EXECUTE THE EXECUTE THE SET ALL STATE SET ALL STATE SET ALL STATE SUBSEMIST AND SET ARE SET AND THE SET AND SET AND SET AND SET A SUBSEMBED AND SUBSEM OF A SUBSTANCE OF A SUBSTANCE OF A SUBSTANCE OF A SUBSTANCE OF A SUBS** which the thermal radiation is maximum and (d) identify the type of electromagnetic wave corresponding to that wavelength.

••35 Calculate the Compton wavelength for (a) an electron and $\frac{\text{the}}{\text{c}}$ Does the classical expression agree with the Planck expression Compton shift in these various regions of the electromagnetic of electromagnetic wave correspond
photon – electron counter?
photon energy loss in a single
 $\frac{44}{4}$ GB For the thermal radiation
photon – electron encounte ••44 G For the thermal radiation from an ideal blackbody radi-**EXECTE THE EXECT THE SET ASSET ASSAUTE THE SURFACT THE SURFACT SURFACT AND MONOK THE SURFACT AND A SURFACT AND A SURFACT AND A SURFACT AND THE METHOD OF CHECTOM SURFACT THE AND THE SURFACT OF 2000 K, let It Is the surfac** ator with a surface temperature of 2000 K, let I_c represent the intensity per unit wavelength according to the classical expression for the spectral radiancy and I_P represent the corresponding intensity per unit wavelength according to the Planck expression. What **EXECUTE THES** 1183

ion is almost immediately absorbed by the surrounding air mole-

cules, which produces another ideal blackbody radiator with a sur-

face temperature of about 1.0×10^5 K. (c) Find the wavelength a is the ratio I_c/I_p for a wavelength of (a) 400 nm (at the blue end of the visible spectrum) and (b) 200 μ m (in the far infrared)? tion is almost immediately absorbed by the surrounding air mole-
cules, which produces another ideal blackbody radiator with a sur-
face temperature of about 1.0 × 10⁵ K. (c) Find the wavelength at
which the thermal ra in the shorter wavelength range or the longer wavelength range? of electromagnetic wave corresponding to that wavelength.
 •44 \bullet For the thermal radiation from an ideal blackbody radiator with a surface temperature of 2000 K, let I_c represent the intensity per unit wavelength a **44 CD** For the thermal radiation from an ideal blackbody radiator with a surface temperature of 2000 K, let I_c represent the intensity per unit wavelength according to the classical expression for the spectral radiancy

•• 45 Assuming that your surface temperature is 98.6°F and that power at which you emit thermal radiation in a wavelength range ator with a surface temperature of 2000 K, let I_c represent the in-
tensity per unit wavelength according to the classical expression
for the spectral radiancy and I_p represent the corresponding inten-
sity per unit w e m-
ssion
tten-
What
d of
ced)?
ssion
nge?
that
that
) the
ange
, and
that
ecal-
have (c) the corresponding rate at which you emit photons from that for the spectral radiancy and I_P represent the corresponding intensity per unit wavelength according to the Planck expression. What is the ratio I_c/I_P for a wavelength of (a) 400 nm (at the blue end of the visible spec sity per unit wavelength according to the Pianck expression. What
is the ratio I_c/I_p for a wavelength of (a) 400 nm (at the blue end of
the visible spectrum) and (b) 200 μ m (in the far infrared)?
(c) Does the classica noticed,you do not visibly glow in the dark.) (c) Does the classical expression agree with the Planck expression
in the shorter wavelength range or the longer wavelength range?
 ••45 Assuming that your surface temperature is 98.6°F and that
you are an ideal blackbo in the shorter wavelength range or the longer wavelength range?
 •45 Assuming that your surface temperature is 98.6°F and that

you are an ideal blackbody radiator (you are close), find (a) the

wavelength at which you **••45** Assuming that your surface temperature is 98.6°F and that you are an ideal blackbody radiator (you are close), find (a) the wavelength at which your spectral radiation in a wavelength range of 1.00 nm at that wavel you are an ideal blackbody radiator (you are close), find (a) the wavelength at which you emit thermal radiation in a wavelength range of 1.00 nm at that wavelength, from a surface area of 4.00 cm², and (c) the correspo wavelength at which your spectral radiancy is maximum, (b) the
power at which you emit thermal radiation in a wavelength range
of 1.00 nm at that wavelength, from a surface area of 4.00 cm², and
area. Using a wavelength power at which you emit thermal radiation in a wavelength range
of 1.00 nm at that wavelength, from a surface area of 4.00 cm², and
area. Using a wavelength of 500 nm (in the visible range), (d) recal-
culate the power

V.47 SSM In an old-fashioned television set, electrons are acceler-

a free electron so that the photon loses 10% of its energy?
be obtained using 100 keV gamma rays? ••48 The smallest dimension (resolving power) that can be resolved by an electron microscope is equal to the de Broglie wavelength of its electrons.What accelerating voltage would be required for the electrons to have the same resolving power as could **Module 38-5 Electrons and Matter Waves**
 Module 38-5 Electrons and Matter Waves
 46 Calculate the de Broglie wavelength of (a) a 1.00 keV electron, (b) a 1.00 keV photon, and (c) a 1.00 keV neutron.
 47 SSM In an o **46** Calculate the de Broglie wavelength of (a) a 1.00 keV electron, (b) a 1.00 keV photon, and (c) a 1.00 keV neutron.
 47 SSM In an old-fashioned television set, electrons are accelerated through a potential differenc **•47 SSM** In an old-fashioned television set, electrons are accelerated through a potential difference of 25.0 kV. What is the de Broglie wavelength of such electrons? (Relativity is not needed.) ••48 The smallest dimensi

••49 SSM WWW Singly charged sodium ions are accelerated acquired by such an ion? (b) What is its de Broglie wavelength?

Module 38-4 The Birth of Quantum Physics greater than its rest energy.) (a) What is λ ? (b) If the target nucleus Broglie wavelength λ small enough for them to probe the structure de Broglie wavelength of such electrons? (Relativity is not needed.)
 ••48 The smallest dimension *(resolving power)* that can be resolved by an electron microscope is equal to the de Broglie wavelength of its electrons that the energy is so large that the extreme relativistic relation $p =$ resolved by an electron microscope is equal to the de Broglie wavelength of its electrons. What accelerating voltage would be required for the electrons to have the same resolving power as could be obtained using 100 keV wavelength of its electrons. What accelerating voltage would be required for the electrons to have the same resolving power as could
be obtained using 100 keV gamma rays?
 ••49 SSM WWW Singly charged sodium ions are acc quired for the electrons to have the same resolving power as could
be obtained using 100 keV gamma rays?
 ••49 SSM WWW Singly charged sodium ions are accelerated
through a potential difference of 300 V. (a) What is the **Example 100** keV gamma rays?
 Example 100 keV gamma rays?
 Example 100 keV gamma rays?
 Example 10 for the ratio R for the momentum

acquired by such an ion? (b) What is its de Broglie wavelength?
 Example 10 Ele through a potential difference of 300 V. (a) What is the momentum
acquired by such an ion? (b) What is its de Broglie wavelength?
 •50 Electrons accelerated to an energy of 50 GeV have a de

Broglie wavelength λ smal ••50 Electrons accelerated to an energy of 50 GeV have a de
Broglie wavelength λ small enough for them to probe the structure
within a target nucleus by scattering from the structure. Assume
that the energy is so large within a target nucleus by scattering from the structure. Assume
that the energy is so large that the extreme relativistic relation $p = E/c$ between momentum magnitude p and energy E applies. (In
this extreme situation, the that the energy is so large that the extreme relativistic relation $p = E/c$ between momentum magnitude p and energy E applies. (In this extreme situation, the kinetic energy of an electron is much greater than its rest

•• 51 SSM The wavelength of the yellow spectral emission line of that wavelength as its de Broglie wavelength?

rected into a two-slit experiment where the slit separation is $4.00 \times$ second minimum (to either side of the center)? this extreme situation, the kinetic energy of an electron is much
greater than its rest energy.) (a) What is λ ? (b) If the target nucleus
has radius $R = 5.0$ fm, what is the ratio R/λ ?
 ••51 SSM The wavelength of t greater than its rest energy.) (a) What is λ ? (b) If the target nucleus
has radius $R = 5.0$ fm, what is the ratio R/λ ?
 ••51 SSM. The wavelength of the yellow spectral emission line of
sodium is 590 nm. At what kin has radius $R = 5.0$ fm, what is the ratio R/λ ?
 ••51 SSM The wavelength of the yellow spectral emission line of sodium is 590 nm. At what kinetic energy would an electron have that wavelength as its de Broglie wavelen ••51 **SSM** The wavelength of the yellow spectral emission line of sodium is 590 nm. At what kinetic energy would an electron have that wavelength as its de Broglie wavelength?

••52 A stream of protons, each with a speed