

Q36: Which of the following types of electromagnetic radiation has photons that have the greatest energy?

Low f High f
RMSVVXG

- a) X-ray
- b. Infrared
- c. Ultraviolet
- d. Microwave

Q37: In a Michelson-type experiment, a stationary mirror and a rotating mirror are separated by 10.0 km. The **lowest** frequency at which a 12-sided rotating mirror must rotate to provide measurements useful in determining the speed of light, expressed in scientific notation, is $a.bc \times 10^d$ Hz. The values of a , b , c , and d are ____, ____, ____, and ____. (2 marks)

(Record your **four digit** answer in the Numerical Response boxes below)

1	2	5	3
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$$v = \frac{c}{t}$$

$$3.0 \times 10^8 = \frac{20,000}{t}$$

$$t = 6.6 \times 10^{-5} \text{ s for } \frac{1}{12} \text{th of a rotation.}$$

$$T = 12(6.6 \times 10^{-5}) = 8.0 \times 10^{-4} \text{ s}$$

$$f = \frac{1}{T} = 1250 \text{ Hz} = 1.25 \times 10^3 \text{ Hz}$$

Q38: The image formed by an object placed 12.0 cm in front of a convex mirror, which has a focal length of 10.0 cm, is

positive f

- a) Real, erect, and smaller
- b) Real, inverted, and larger**
- c) Virtual, erect, and smaller
- d) Virtual, inverted, and larger

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$\frac{1}{+10} = \frac{1}{d_i} + \frac{1}{12}$$

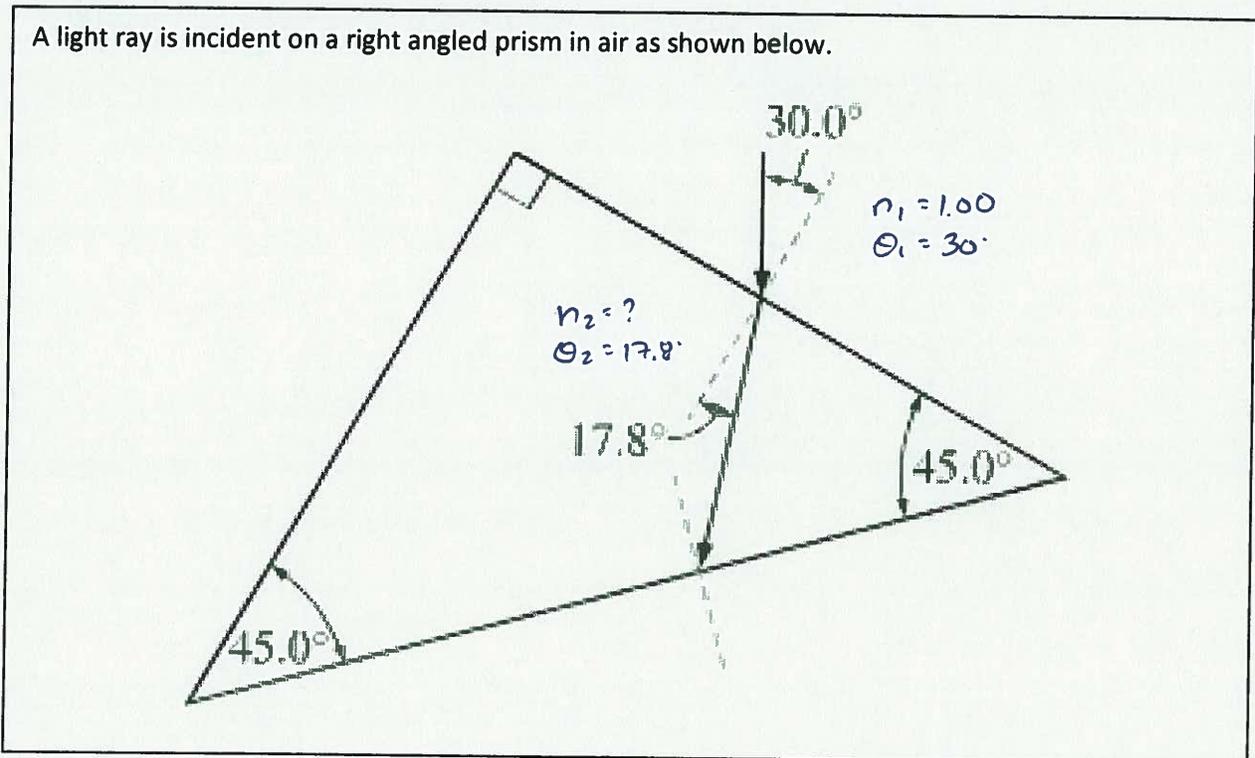
$$d_i = 60 \text{ cm}$$

$$m = \frac{-d_i}{d_o} = \frac{-60}{12} = -5x$$

↙
↘

Inverted Enlarged

Use the following information to answer Q39:



Q39: The index of refraction of the prism shown above is

- a. 1.69
- b. 1.64
- c. 0.611
- d. 0.593

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1}$$

$$\frac{\sin 30.0}{\sin 17.8} = \frac{n_2}{1.00}$$

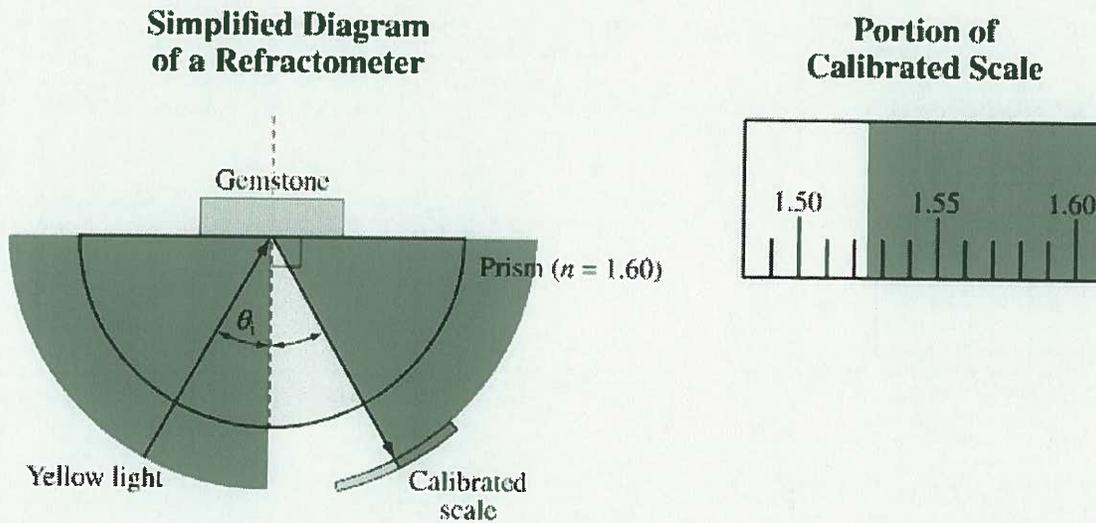
$$n_2 = 1.64$$

Use the following information to answer Q40:

A refractometer is a device that can be used to identify gemstones by determining their index of refraction.

In one type of refractometer, a gemstone is located against the flat edge of a semi-spherical prism, as shown below. The index of refraction of the prism is 1.60.

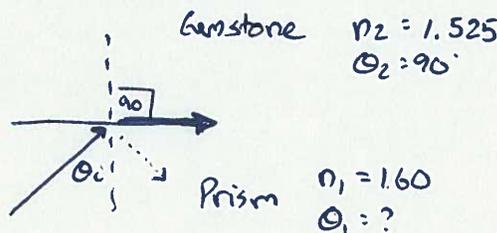
Monochromatic yellow light that has a wavelength of 589 nm is directed so that it passes through the prism and meets the prism-gemstone interface. When the angle of incidence, θ_i , is large enough, the light does not refract into the gemstone, and is reflected. This light leaves the prism through a curved edge and is incident on a calibrated scale. The yellow light illuminates the scale, indicating the index of refraction of the gemstone.



Note: The diagram of the refractometer is **not** drawn to scale.

Q40: The critical angle of the prism-gemstone interface is

- a) 2.44°
- b) 17.6°
- c) 72.4°
- d) 90.0°



$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1}$$

$$\frac{\sin \theta_1}{\sin 90} = \frac{1.525}{1.60}$$

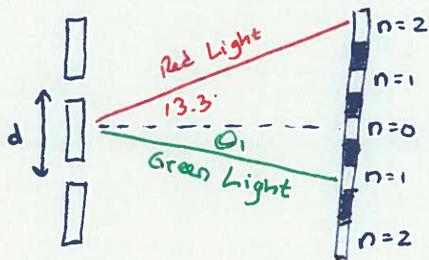
$$\theta_1 = 72.4^\circ$$

Use the following information to answer Q41:

A laser pointer emits red light that has a wavelength of 6.50×10^{-7} m. A different laser pointer emits green light that has a wavelength of 4.80×10^{-7} m. Light from both lasers is incident on a diffraction grating, and interference patterns are produced on a screen 1.00 m from the diffraction grating. The angle of diffraction to the **second** order maximum for the **red** light is 13.3° .

Q41: The angle of diffraction to the **first** order maximum for the **green** light is

- a) 2.44°
- b) 4.87°**
- c) 9.78°
- d) 13.3°



Red Light

$$\lambda = \frac{d \sin \theta}{n}$$

$$6.50 \times 10^{-7} = \frac{d \sin 13.3}{2}$$

$$d = 5.65095 \times 10^{-6} \text{ m}$$

Green Light

$$\lambda = \frac{d \sin \theta}{n}$$

$$4.80 \times 10^{-7} = \frac{(5.65095 \times 10^{-6}) \sin \theta}{1}$$

$$\theta_1 = 4.87^\circ$$

Q42: An object is placed 20.0 cm in front of a curved mirror. The image that forms is inverted and larger than the object. The type of mirror used and its focal length are, respectively,

- Convex and 15.0 cm
- Convex and 30.0 cm
- Concave and 15.0 cm**
- d. Concave and 30.0 cm

Image is inverted? Must be concave.
(Convex images are always virtual, erect, diminished)

Test #1

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$\frac{1}{15} = \frac{1}{20} + \frac{1}{d_i}$$

$$d_i = 60 \text{ cm}$$

$$m = \frac{-d_i}{d_o} = \frac{-60}{20} = -3$$

So enlarged and inverted.

Test #2

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$\frac{1}{30} = \frac{1}{20} + \frac{1}{d_i}$$

$$d_i = -60 \text{ (Virtual, because within focal length).}$$

$$m = \frac{-d_i}{d_o} = \frac{-(-60)}{20} = 3$$

So virtual, erect, and enlarged.

NOTE: This question can be done without math by memorizing your ray diagrams.

Q43: The longest wavelength of electromagnetic radiation that will cause electrons to be emitted by a particular surface is 2.70×10^{-7} m. If radiation that has a wavelength of 1.50×10^{-7} m is incident on the surface, the maximum kinetic energy of an emitted electron is

- a) 1.66×10^{-18} J
- b) 1.33×10^{-18} J
- c) 7.37×10^{-19} J
- d) 5.89×10^{-19} J**

$$E_{\text{photon}} \rightarrow W + E_K$$

$$\frac{hc}{\lambda} \rightarrow hf_0 + E_K \quad \text{where } c = f_0 \lambda_0$$

$$\frac{hc}{\lambda} \rightarrow \frac{hc}{\lambda_0} + E_K$$

$$\frac{(6.63 \times 10^{-34})(3 \times 10^8)}{(1.50 \times 10^{-7})} = \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{(2.70 \times 10^{-7})} + E_K$$

$$E_K = 5.893 \times 10^{-19} \text{ J}$$

Use the following information to answer Q44:

Phenomena Demonstrated by Electromagnetic Radiation

- I Diffraction \rightarrow wave
- II Interference \rightarrow wave
- III Compton Scattering \rightarrow Particle
- IV Photoelectric Effect \rightarrow Particle

Q44: Which of the following rows matches the phenomena, as numbered above, with the model of electromagnetic radiation supported by the phenomena?

Row	Particle Model	Wave Model
A.	I and II	III and IV
B.	I and III	II and IV
C.	II and IV	I and III
D.	III and IV	I and II

Use the following information to answer Q45:

In a photoelectric effect experiment, electromagnetic radiation that has a wavelength of 4.00×10^{-7} m is incident on a photocathode that has a work function of 2.50 eV.

The photocurrent produced in the experiment is 2.0×10^{-6} A.

$\rightarrow 4.0 \times 10^{-19} \text{ J}$

Q45: The maximum speed of a photoelectron emitted in the experiment is

- a) 4.61×10^5 m/s
- b) 9.37×10^5 m/s
- c) 1.04×10^6 m/s
- d) 1.40×10^6 m/s

$$E_{\text{photon}} \rightarrow \omega + E_K$$

$$\frac{(6.63 \times 10^{-34})(3 \times 10^8)}{(4.00 \times 10^{-7})} = (4.0 \times 10^{-19}) + E_K$$

$$E_K = 9.725 \times 10^{-20} \text{ J}$$

$$E_K = \frac{1}{2} m v^2$$

$$9.725 \times 10^{-20} = \frac{1}{2} (9.11 \times 10^{-31}) v^2$$

$$v = 4.62 \times 10^5 \text{ m/s}$$

Use the following information to answer Q46:

Light from a source passes through a glass prism and the following spectrum is observed.



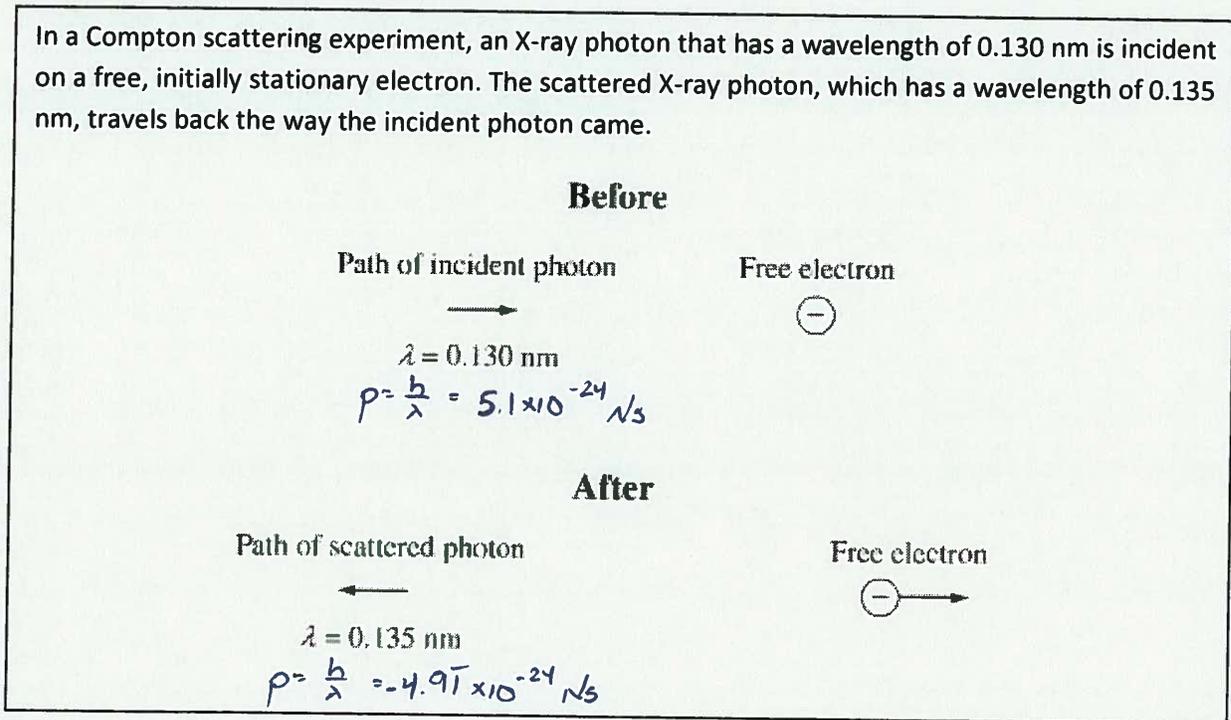
Q46: The prism separates the colors because

- a) Different wavelengths refract to different angles \rightarrow Refraction occurs when going from one medium to another.
- b) Different wavelengths diffract to different angles \rightarrow Diffraction occurs in
- ~~c) There is no change in frequency in refraction~~
- ~~d) There is no change in frequency in diffraction~~



Use the following information to answer Q47:

In a Compton scattering experiment, an X-ray photon that has a wavelength of 0.130 nm is incident on a free, initially stationary electron. The scattered X-ray photon, which has a wavelength of 0.135 nm, travels back the way the incident photon came.



Q47: The magnitude of the final momentum of the electron is

- a) $1.33 \times 10^{-22} \text{ kg}\cdot\text{m/s}$
- b) $1.00 \times 10^{-23} \text{ kg}\cdot\text{m/s}$
- c) $5.10 \times 10^{-24} \text{ kg}\cdot\text{m/s}$
- d) $4.91 \times 10^{-24} \text{ kg}\cdot\text{m/s}$

$$p_i = p_f$$

$$(+5.1 \times 10^{-24}) = (-4.91 \times 10^{-24}) + p_e$$

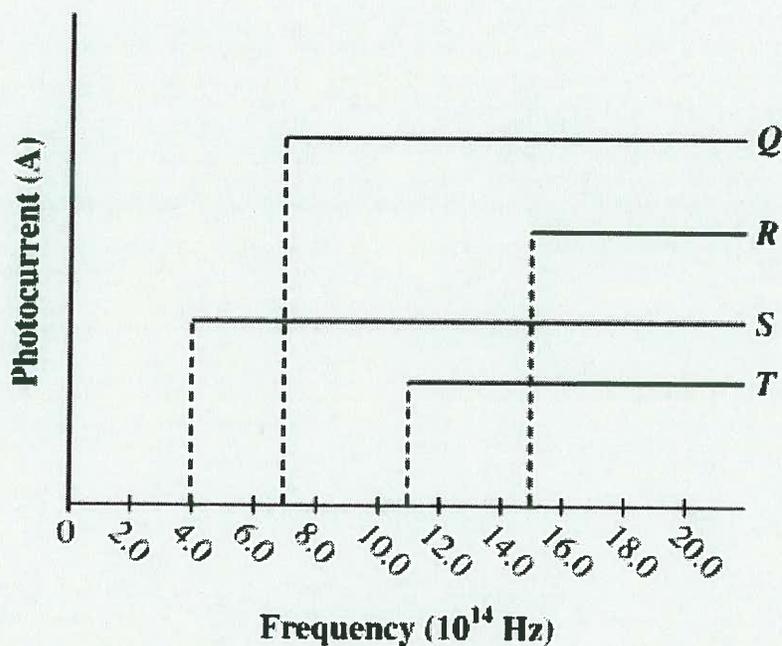
$$p_e = 1.001 \times 10^{-23} \text{ N}\cdot\text{s}$$

$$\approx 1.00 \times 10^{-23} \text{ kg}\cdot\text{m/s}$$

Use the following information to answer Q48:

In a photoelectric effect experiment, electromagnetic radiation (EMR) of varying frequencies is incident on each of four different metals. The intensity of EMR used for each of the metals is different. The resulting photocurrent is measured, and a graph of the results is shown below.

Photocurrent as a Function of Frequency



Q48: When EMR that has a frequency of 8.0×10^{14} Hz is incident on each of the metals, the metal that will emit photoelectrons with the highest kinetic energy is metal

- a) Q
- b) R
- c) S
- d) T

$$E_{\text{photon}} \rightarrow W + E_K$$

$$hf \rightarrow hf_0 + E_K$$

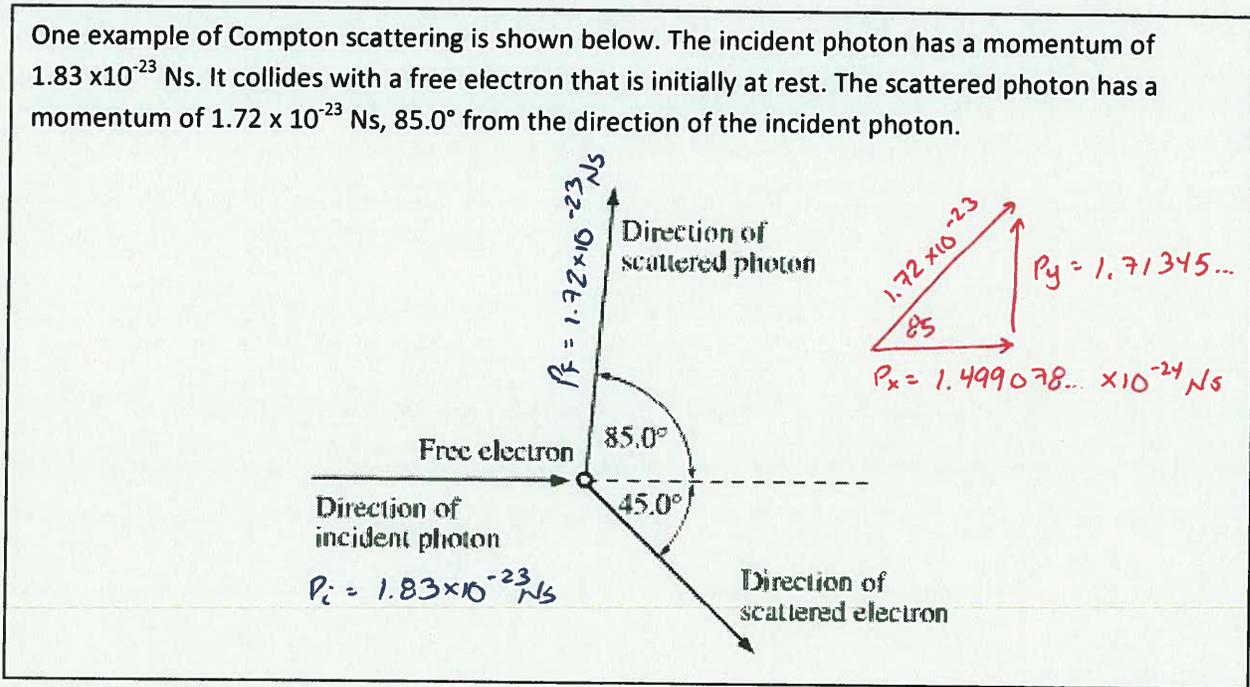
$$hf - hf_0 = E_K$$

$$h(f - f_0) = E_K$$

So the one with the largest E_K is the one with the smallest threshold frequency, f_0 .

Use the following information to answer Q49:

One example of Compton scattering is shown below. The incident photon has a momentum of 1.83×10^{-23} Ns. It collides with a free electron that is initially at rest. The scattered photon has a momentum of 1.72×10^{-23} Ns, 85.0° from the direction of the incident photon.



Q49: The magnitude of the momentum of the free electron after it has been hit by the incident photon is

- a. 1.10×10^{-24} kg*m/s
- b. 1.68×10^{-23} kg*m/s
- c. 1.71×10^{-23} kg*m/s
- d. 2.40×10^{-23} kg*m/s**

x-comp

$$P_i = P_f$$

$$1.83 \times 10^{-23} = 1.499078 \times 10^{-24} + P_{ex}$$

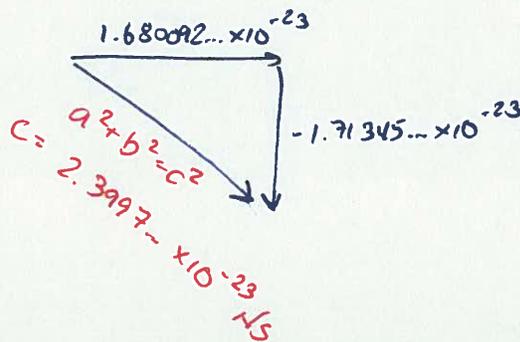
$$P_{ex} = 1.680092 \times 10^{-23} \text{ Ns}$$

y-comp

$$P_i = P_f$$

$$0 = (+1.71345 \times 10^{-23}) + P_{ey}$$

$$P_{ey} = -1.71345 \times 10^{-23}$$



Use the following information to answer Q50-Q51:

In a photoelectric effect experiment, electromagnetic radiation that has a wavelength of $4.00 \times 10^{-7} \text{ m}$ is incident on a photocathode that has a work function of 2.50 eV .

The photocurrent produced in the experiment is $2.0 \times 10^{-6} \text{ A}$.

Q50: The maximum speed of a photoelectron emitted in the experiment is

- a. $4.61 \times 10^5 \text{ m/s}$
- b. $9.37 \times 10^5 \text{ m/s}$
- c. $1.04 \times 10^6 \text{ m/s}$
- d. $1.40 \times 10^6 \text{ m/s}$

Whoops. Repeat of #45.

$$v = 4.62 \times 10^5 \text{ m/s}$$

Q51: The minimum number of photons incident on the photocathode during 0.50 minutes of continuous operation is

- a. 4.2×10^{11} photons
- b. 6.3×10^{12} photons
- c. 1.3×10^{13} photons
- d. 3.8×10^{14} photons

$$I = \frac{q}{t}$$

$$2.0 \times 10^{-6} = \frac{q}{30}$$

$$q = 6.0 \times 10^{-5} \text{ C}$$

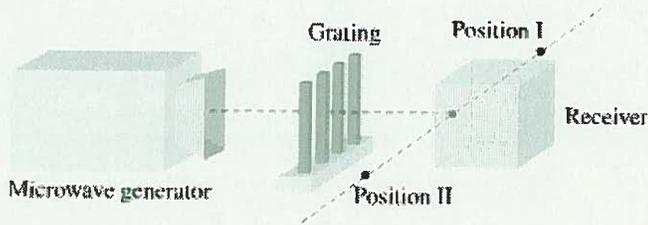
$$q = (3.75 \times 10^{14}) e$$

So 3.75×10^{14} electrons are emitted by 3.75×10^{14} photons.

Use the following information to answer Q52:

In a laboratory experiment, a microwave generator is used to produce a beam of monochromatic microwaves. These waves are incident on a series of metal tubes that forms a diffraction grating. The metal tubes are spaced 1.80 cm apart.

When the microwave signal passes through the grating, a receiver placed 52.0 cm from the grating detects a maximum signal. A first-order maximum signal is also detected at each of positions I and II, as labelled in the diagram below.



Note: This diagram is not to scale.

The angle from the central maximum to either position I or II is 49.8°.

Q52: The experimental wavelength of the microwaves, in centimeters, is _____ cm.

(Record your ^{three} ~~four~~ digit answer in the Numerical Response boxes below)

1	3	7	
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$$\lambda = \frac{d \sin \theta}{n} = \frac{(0.018) \sin 49.8}{1}$$

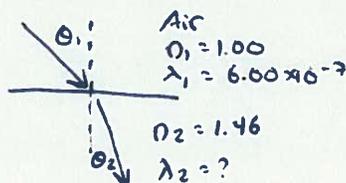
$$\lambda = 1.37 \times 10^{-2} \text{ m}$$

$$\approx 137 \text{ cm}$$

Q53: Visible light that has a wavelength of $6.00 \times 10^{-7} \text{ m}$ in air is directed into fused quartz. The index of refraction of fused quartz is 1.46. The wavelength of this light inside the fused quartz, expressed in scientific notation, is _____ $\times 10^{-7} \text{ m}$.

(Record your **four digit** answer in the Numerical Response boxes below)

4	.	1	1
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$$\frac{n_2}{n_1} = \frac{\lambda_1}{\lambda_2}$$

$$\frac{1.46}{1.00} = \frac{6.00 \times 10^{-7}}{\lambda_2}$$

$$\lambda_2 = 4.1095... \times 10^{-7} \text{ m}$$

$$\approx 4.11 \times 10^{-7} \text{ m}$$

Q54: If a yellow light with a wavelength of 540 nm shines on a double slit with the slits cut 0.0100 mm apart, what is the angle between the central bright spot and the second order antinode?

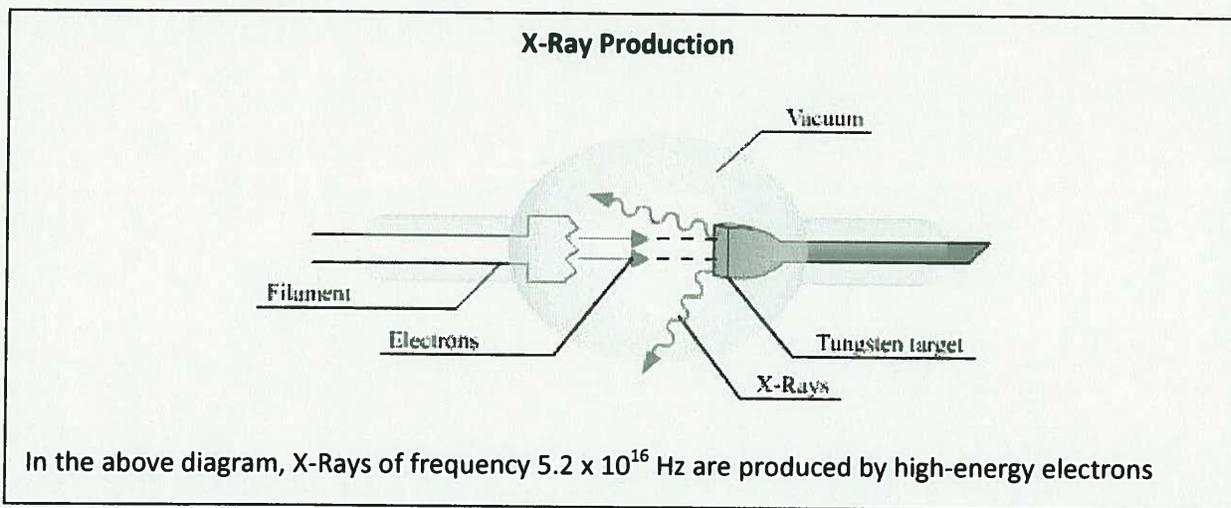
- a. 6.19×10^{-3} deg
- b. 6.19×10^{-2} deg
- c. 3.10 deg
- d.** 6.20 deg

$$\lambda = \frac{d \sin \theta}{n}$$

$$540 \times 10^{-9} = \frac{(0.01 \times 10^{-3}) \sin \theta}{2}$$

$$\theta = 6.20^\circ$$

Use the following diagram to answer Q55:



Q55: The high-energy electrons have a velocity $a.bc \times 10^d$ m/s. The values of a , b , c , and d are ____, ____, ____, and ____. (1 mark)

(Record your **four digit** answer in the Numerical Response boxes below)

8 7 0 6

$$E_p \rightarrow E_k \rightarrow E_{\text{photon}}$$

$$\frac{1}{2}mv^2 = hf$$

$$\frac{1}{2}(9.11 \times 10^{-31})v^2 = (6.63 \times 10^{-34})(5.2 \times 10^{16})$$

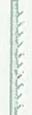
$$v = 8.699899 \times 10^6 \text{ m/s}$$

$$v \approx 8.70 \times 10^6 \text{ m/s}$$

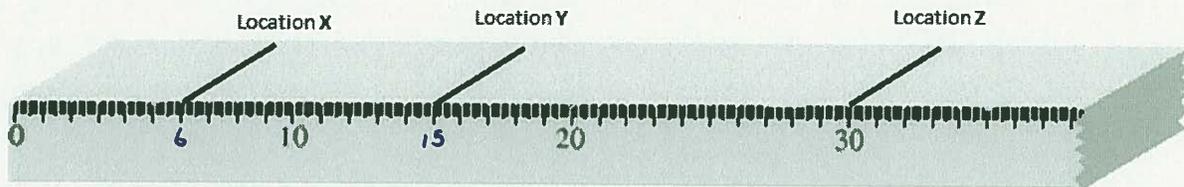
Use the following information to answer Q56:

Students use three of the optical apparatus illustrated below to produce a **focused, real image** in a darkened room. One of the apparatus has a focal length of **6.55 cm**.

Optical Apparatus

Sources		Lenses		Mirrors			Diffraction grating	Double-slit apparatus	Screen
									
0	1	2	3	4	5	6	7	8	9

The students place one apparatus at each labelled location on an optics bench, as shown below. The optics bench is scaled in millimeters and labelled in centimeters.



Note: The diagrams are **not** drawn to scale.

Q56: The apparatus placed at location

X is numbered _____ (Record in the **first** column)

Y is numbered _____ (Record in the **second** column)

Z is numbered _____ (Record in the **third** column)

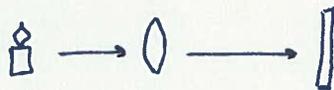
(Record your **four digit** answer in the Numerical Response boxes below)

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Multiple Answers Available

- | | | | |
|---|---|---|--|
| 4 | 9 | 0 | |
|---|---|---|--|
- | | | | |
|---|---|---|--|
| 4 | 9 | 1 | |
|---|---|---|--|
- | | | | |
|---|---|---|--|
| 4 | 0 | 9 | |
|---|---|---|--|
- | | | | |
|---|---|---|--|
| 4 | 1 | 9 | |
|---|---|---|--|

Option #1



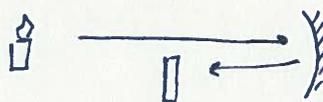
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$\frac{1}{f} = \frac{1}{9} + \frac{1}{15}$$

$$f = 5.62 \text{ cm}$$

Nope!

Option #2



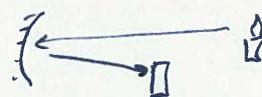
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$\frac{1}{f} = \frac{1}{24} + \frac{1}{15}$$

$$f = 9.23 \text{ cm}$$

Nope!

Option #3

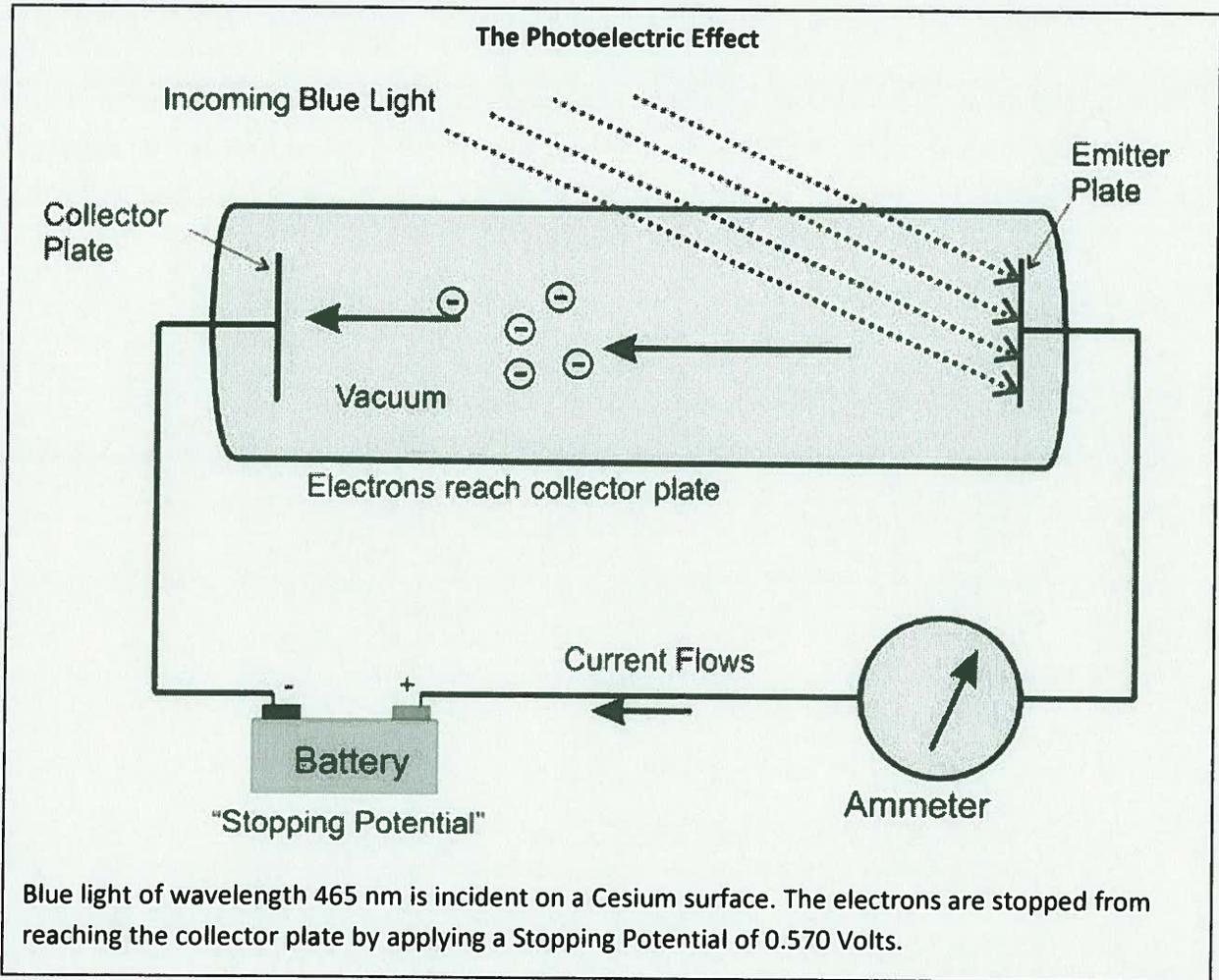


$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$\frac{1}{f} = \frac{1}{24} + \frac{1}{9}$$

$$f = 6.55 \text{ cm} \quad \text{Yup!}$$

Use the following to answer Q57:



Q57: What is the work function of the Cesium target, in eV?

(Record your ^{three} ~~four~~ digit answer in the Numerical Response boxes below)

2	.	1	0
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$$E_{\text{photon}} \rightarrow W + E_k \quad \text{where } E_k \rightarrow E_p$$

$$\frac{hc}{\lambda} \rightarrow W + q\Delta V$$

$$\frac{(4.14 \times 10^{-15})(3 \times 10^8)}{(465 \times 10^{-9})} = W + (1e)(0.570 \text{ V})$$

$$2.87 \dots \text{ eV} = W + 0.570 \text{ eV}$$

$$W = 2.10 \text{ eV}$$

Use the following information to answer Q58:

When a girl who is 122 cm tall stands 40 cm in front of a particular mirror, her virtual image in the mirror is upright and 54 cm tall.

Q58: The mirror is i, and the girl's image is located ii away from the mirror.

	i	ii
A.	convex	18 cm
B.	convex	90 cm
C.	concave	18 cm
D.	concave	90 cm

OBJECT	IMAGE
$h_o = 122 \text{ cm}$	$d_i = \text{negative}$
$d_o = 40 \text{ cm}$	$h_i = 54 \text{ cm}$

So image is virtual, erect, and diminished.

$$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$\frac{54}{122} = \frac{-d_i}{40}$$

$$d_i = -17.7 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$\frac{1}{f} = \frac{1}{40} + \frac{1}{-17.7}$$

$$f = -31.76 \text{ cm}$$

↓
Convex

Q59: An electron is accelerated from rest using an accelerating voltage of $a.bc \times 10^d$ Volts and collides with a tungsten target to generate an X-Ray of energy 4.8×10^{-17} J. The values of a , b , c , and d are _____, _____, and _____. (1 mark)

(Record your four digit answer in the Numerical Response boxes below)

3 0 0 2

$$E_p \rightarrow E_k \rightarrow E_{\text{photon}}$$

$$q \Delta V \longrightarrow E_{\text{photon}}$$

$$(1.60 \times 10^{-19})(\Delta V) = (4.80 \times 10^{-17})$$

$$\Delta V = 300 \text{ V}$$

$$= 3.00 \times 10^2 \text{ V}$$