

First Name: \_\_\_\_\_

Last Name: \_\_\_\_\_

L11 - Worksheet - EMR as Waves

**L01 - EMR**

**Q1:** An electromagnetic wave travels vertically upward, perpendicular to Earth's surface. If the magnetic field component of the wave oscillates in a north-south direction, then the electric field component will oscillate in

- a. An east-west direction
- b. A north-south direction
- c. A vertically upward direction
- d. A vertically downward direction.

Use the following information to answer Q2:

Types of EMR	
1	Blue light ✓
2	Gamma radiation G
3	Radio waves R
4	Ultraviolet radiation U

**Q2:** When the types of EMR above are listed in order from the lowest frequency to the highest frequency, the order is \_\_, \_\_, \_\_, \_\_.

(Record you **four-digit** answer in the numerical response boxes below.)

Low f  $\longrightarrow$  High f

R M I V U X G  
3      1 4      2

3	1	4	2
---	---	---	---

Use the following information to answer Q3-Q4:

**Radio Telescopes**

Radio telescopes detect radio waves emitted by objects throughout the universe. They do not detect the visible light from stars and galaxies.

The Dominion Radio Astrophysical Observatory (DRAO), located in Penticton, BC, has a seven-antenna radio telescope. Using signals from this telescope, DRAO produces detailed wide-angle pictures of the radio sky.

One of the radio waves that this telescope can detect has a frequency of 1.420 MHz that comes from an arm of the Milky Way Galaxy that is  $7.00 \times 10^{18}$  km away.

**Q3:** The amount of time, in days, that it takes the radio waves detected by the telescope to reach Earth is

- a.  $2.7 \times 10^8$  days
- b.  $6.5 \times 10^9$  days
- c.  $2.3 \times 10^{13}$  days
- d.  $2.0 \times 10^{18}$  days

$$v = \frac{d}{t} \quad \text{or} \quad t = \frac{d}{v} = \frac{7.00 \times 10^{18} \times 10^3 \text{ m}}{3.0 \times 10^8 \text{ m/s}}$$

$$t = 2.3 \times 10^{13} \text{ seconds}$$

$$= 3.8 \times 10^{11} \text{ min}$$

$$= 6.48 \dots \times 10^9 \text{ hrs}$$

$$= 2.70 \times 10^8 \text{ days.}$$

**Q4:** DRAO is located in a basin surrounded by mountains, which shield it from manmade radio waves that interfere with astronomical signals. Manmade radio waves are produced by

- a. Radioactive decay
- b. Electron transitions in atoms
- c. Oscillating charges in a linear antenna
- d. High speed electrons stopped suddenly by a metal surface

Use the following information to answer Q5:

In 1991, the 18.0 GHz region of the electromagnetic spectrum was used to provide communication links in local area networks (LANs). This led to a dramatic expansion of this region's commercial use.

**Q5:** The wavelength of an 18.0 GHz wave, expressed in scientific notation, is  $a.bc \times 10^{-d}$  m, where  $a$ ,  $b$ ,  $c$ , and  $d$  are \_\_, \_\_, \_\_, and \_\_.

(Record your **four-digit** answer in the numerical response boxes below.)

1	6	7	2
---	---	---	---

$$v = f\lambda$$

$$(3.0 \times 10^8) = (18.0 \times 10^9) \lambda$$

$$f = 1.6666 \times 10^{-2} \text{ Hz}$$

$$\approx 1.67 \times 10^{-2} \text{ Hz}$$

**Q6:** The correct order of electromagnetic radiation, listed in order of **lowest** to **highest** frequency, is

- a) Radio waves, x-rays, infrared
- b) Visible, ultraviolet, radio waves
- c) Microwaves, ultraviolet, x-rays
- d) Radio waves, ultraviolet, infrared

Low f  $\longrightarrow$  High f  
R M I V U X G

**Q7:** The direction of electromagnetic wave propagation is

x	I	parallel to the electric field
✓	II	perpendicular to the electric field
x	III	parallel to the magnetic field
✓	IV	perpendicular to the magnetic field

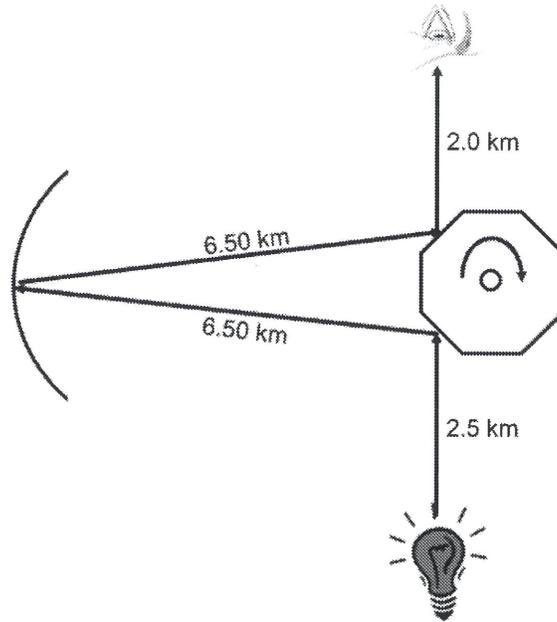
The correct combination of choices is

- a) I only
- b) III only
- c) I and III only
- d) II and IV only

L02 – Speed of Light

Use the following information to answer Q8:

Michelson used a rotating octagonal mirror to measure the speed of light. Below is a smaller scale version of this experiment.



**Q8:** In the diagram above, light is first observed when the minimum rotational frequency of the octagonal mirror, written in scientific notation, is  $b \times 10^w$  Hz. The value of  $b$  is \_\_\_\_\_.

(Record your **three-digit** answer in the numerical response boxes below.)

2	.	89
---	---	----

$$v = \frac{d}{t} = \frac{13,000 \text{ m}}{t}$$

$$3.0 \times 10^8 = \frac{13,000}{t}$$

$$t = 4.3 \times 10^{-5} \text{ s} \Rightarrow \text{Time for } \frac{1}{8} \text{th of a rotation.}$$

Full rotational period is 8x bigger.

$$T = 3.45 \times 10^{-4} \text{ s}$$

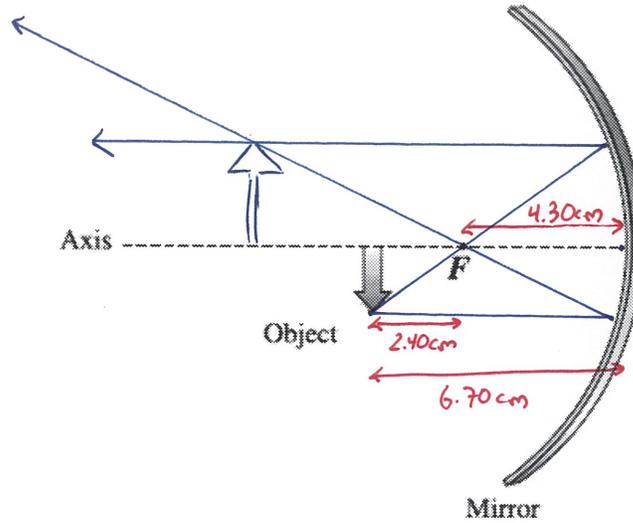
$$f = \frac{1}{T} = 2884.6 \text{ Hz}$$

$$\approx 2.89 \times 10^3 \text{ Hz}$$

L03&04 – Reflection Ray Diagrams and Equations

Use the following information to answer Q9:

A concave mirror, its central axis, and an object are shown in the diagram below.



The distance from the object to the focal point is 2.40 cm and the focal length of the mirror is 4.30 cm.

Q9: The distance from the image to the mirror is

- a. 0.0833 cm
- b. 0.184 cm
- c. 5.43 cm
- d. 12.0 cm

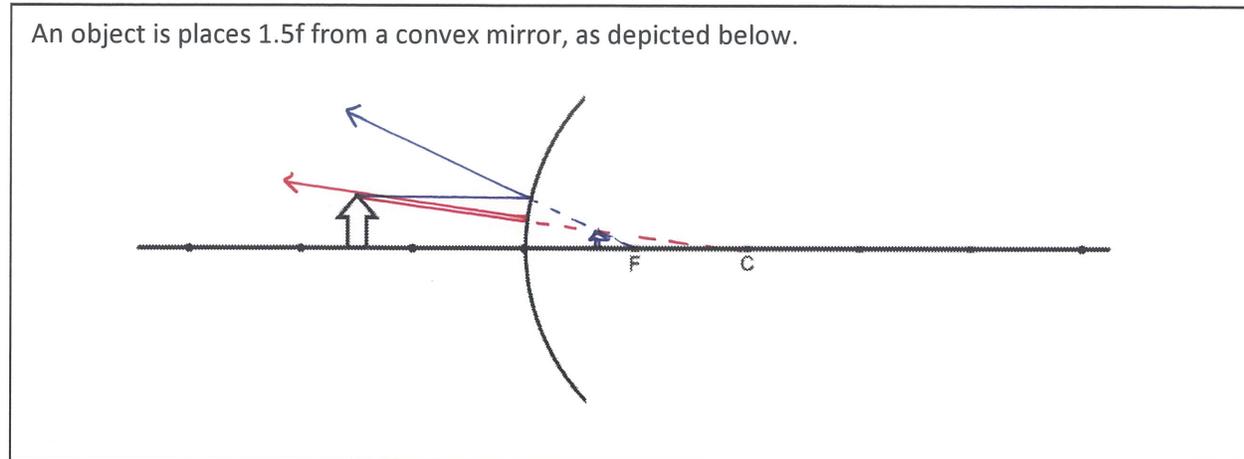
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$\frac{1}{4.30} = \frac{1}{6.70} + \frac{1}{d_i}$$

$$d_i = 12.0 \text{ cm}$$

Could have also been estimated from ray diagram.

Use the following information to answer Q10:



Q10: Which of the following statements best describe the image?

×	<b>I</b>	The image is real
✓	<b>II</b>	The image is virtual
×	<b>III</b>	The image is enlarged
✓	<b>IV</b>	The image is diminished
✓	<b>V</b>	The image is erect
×	<b>VI</b>	The image is inverted

- a) **I, III, V**
- b) **II, IV, VI**
- c) **I, III, VI**
- (d) II, IV, V**

L05 - Refraction

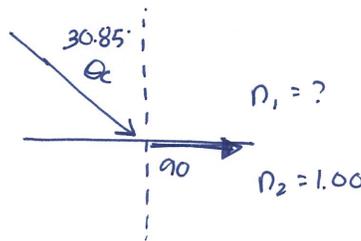
Use the following information to answer Q11:

The properties of diamond and popular diamond substitutes are listed in the table below.

Stone	Cubic zirconia	Synthetic corundum	Zirconium silicate	Diamond
Hardness (Mohs)	8.5	9	7.5	10
Density (g/cm <sup>3</sup> )	5.5 - 5.9	4.02	4.6 - 4.7	3.52
Composition	ZrO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	ZrSiO <sub>4</sub>	C
Refractive Index	Approximately 2.17	1.762 - 1.770	1.925 - 1.961 1.95	2.417

Q11: A stone is observed in air to experience total internal reflection at an angle of 30.85° from the normal. The stone must therefore be:

- a) Cubic zirconia
- b) Synthetic corundum
- c) Zirconium silicate
- d) Diamond



$$n_1 \sin \theta_c = n_2 \sin \theta_2$$

$$n_1 \sin 30.85 = (1.0) \sin 90$$

$$n_1 = 1.95$$

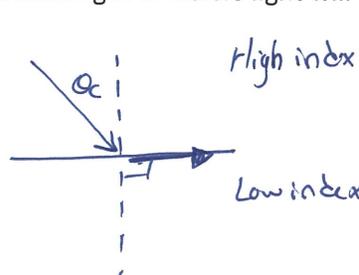
Use the following information to answer Q12:

A group of students conducts a series of tests to determine which combination of optical media results in the largest critical angle for one wavelength of visible light. The table below lists the index of refraction for each of the media used.

Medium Used	Index of Refraction for this Wavelength of Visible Light
Water	1.33
Glass	1.46
Quartz	1.54
Flint Glass	1.70

Q12: The largest critical angle for this wavelength of visible light will be produced for the path from

- a. Glass to quartz
- b. Quartz to glass
- c. Water to flint glass
- d. Flint glass to water



Quartz to Glass

$$n_1 \sin \theta_c = n_2 \sin \theta_2$$

$$(1.54) \sin \theta_c = (1.46) \sin 90$$

$$\theta_c = 71.5^\circ$$

Flint Glass to Water

$$n_1 \sin \theta_c = n_2 \sin \theta_2$$

$$(1.70) \sin \theta_c = (1.33) \sin 90$$

$$\theta_c = 51.5^\circ$$

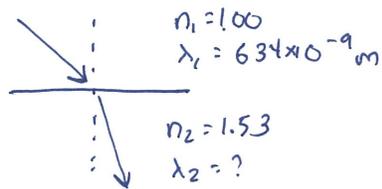
Use the following information to answer Q13 and Q17

A student follows three procedures to study the properties of laser light. She uses a laser that emits monochromatic light that has a wavelength of 634 nm.

	Procedure	Observation
I	The student first shines the laser light through the crystal that has an index of refraction of 1.53.	The path of the refracted ray is recorded.
II	The student shines the laser light through a diffraction grating that has $5.00 \times 10^5$ lines/m.	An interference pattern is projected onto a screen.
III	The student shines the laser light upon a photovoltaic cell that is connected to an ammeter.	No electrical current is measured.

**Q13:** In procedure I, the wavelength of the laser light in the crystal is i. The speed of the laser light in the crystal is ii than its speed in air.

	i	ii
<b>A.</b>	$4.14 \times 10^{-7}$ m	less
B.	$4.14 \times 10^{-7}$ m	greater
C.	$9.70 \times 10^{-7}$ m	less
D.	$9.70 \times 10^{-7}$ m	greater



$$\frac{n_2}{n_1} = \frac{\lambda_1}{\lambda_2}$$

$$\frac{1.53}{1.00} = \frac{634 \times 10^{-9}}{\lambda_2}$$

$$\lambda_2 = 4.14 \times 10^{-7} \text{ m}$$

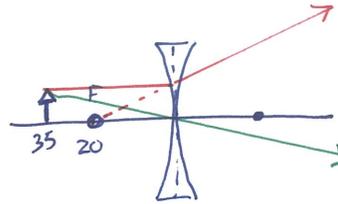
I could calculate the speed of light in the crystal, but I know that light slows down through high index materials.

L06 – Refraction Lenses

Q14: An object is placed 35.0 cm from a diverging lens that has a focal length of 20.0 cm. The image produced is

- a. Real and larger than the object
- b. Real and smaller than the object
- c. Virtual and larger than the object
- d. Virtual and smaller than the object

Always true for a diverging lens.



Q15: An object of height 3cm is placed 15cm from a converging lens of focal length 12cm. The height of the image is:

- a) -12cm
- b) -4cm
- c) 0.8cm
- d) 60cm

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

$$m = \frac{-d_i}{d_o} = \frac{-60}{15} = -4$$

$$\frac{1}{12} = \frac{1}{15} + \frac{1}{d_i}$$

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

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

$$\frac{h_i}{3} = \frac{-60}{15}$$

$$h_i = -12 \text{ cm}$$

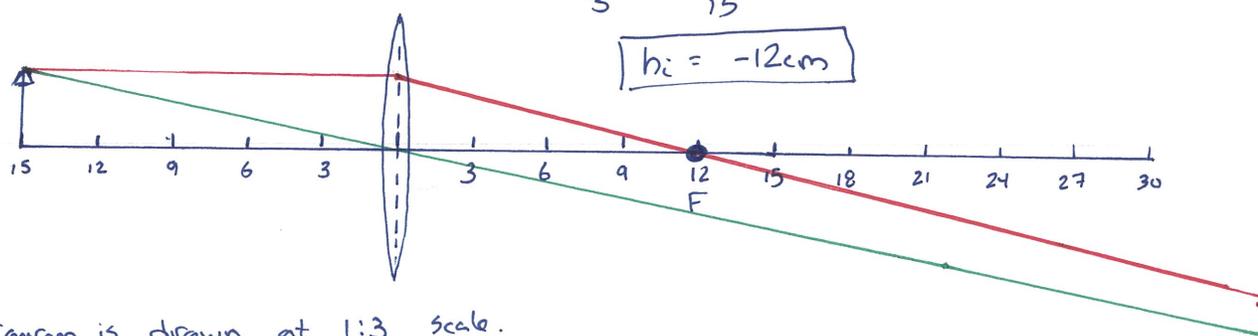
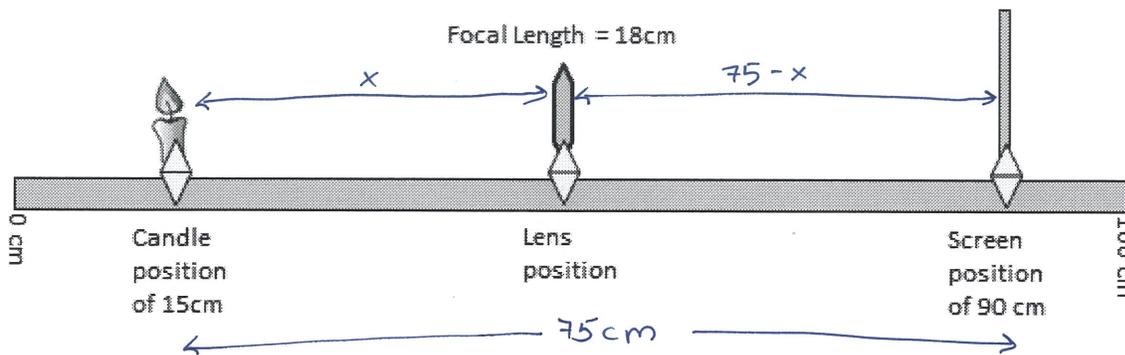


Diagram is drawn at 1:3 scale.  
Image height will be negative and enlarged.

L07 – Refraction Lenses Graphing and Optics Rails

Use the following information to answer Q16:

A 100-cm meter stick is used to create an optics rail. The candle is placed at a position of 15cm, and the screen at a position of 90cm. The converging lens has a focal length of 18cm.



Students discover that there are two different positions that the lens can be placed that create a real, focused image on the screen.

**Q16:** The two positions that the lens can be placed to create a real, focused image are at **ab** centimeters, and at **cd** centimeters, where **a**, **b**, **c**, and **d** are \_\_, \_\_, \_\_, and \_\_.

(Record your **four-digit** answer in the numerical response boxes below.)

4	5	6	0
---	---	---	---

 or 

6	0	4	5
---	---	---	---

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

$$\frac{1}{18} = \frac{1}{x} + \frac{1}{75-x}$$

$$\frac{1}{18} \cdot \frac{(x)(75-x)}{(x)(75-x)} = \frac{1}{x} \cdot \frac{(18)(75-x)}{(18)(75-x)} + \frac{1}{75-x} \cdot \frac{(x)(18)}{(x)(18)}$$

$$\frac{75x - x^2}{(18)(x)(75-x)} = \frac{1350 - 18x}{(18)(x)(75-x)} + \frac{18x}{(18)(x)(75-x)}$$

$$75x - x^2 = 1350 - 18x + 18x$$

$$0 = x^2 - 75x + 1350$$

$$0 = (x-45)(x-30)$$

$$\begin{matrix} \downarrow & & \downarrow \\ x=45 & \text{or} & x=30 \end{matrix}$$

So  $d_o = 45\text{cm}$  or  $30\text{cm}$  from vertex of lens.

lens positioned at  $15+30=45\text{cm}$  or  $45+15=60\text{cm}$

**L09 – Diffraction, Interference, and Polarization**

Use the following information to answer Q13 and Q17:

A student follows three procedures to study the properties of laser light. She uses a laser that emits monochromatic light that has a wavelength of 634 nm.

	<b>Procedure</b>	<b>Observation</b>
<b>I</b>	The student first shines the laser light through the crystal that has an index of refraction of 1.53.	The path of the refracted ray is recorded.
<b>II</b>	The student shines the laser light through a diffraction grating that has $5.00 \times 10^5$ lines/m.	An interference pattern is projected onto a screen.
<b>III</b>	The student shines the laser light upon a photovoltaic cell that is connected to an ammeter.	No electrical current is measured.

**Q17:** In procedure **II**, the angle between the central maximum and the first bright spot of the interference pattern is \_\_\_\_\_°.

$n=1$

(Record your **three-digit** answer in the numerical response boxes below.)

1	8	.	5
---	---	---	---

$$\frac{5.00 \times 10^5 \text{ lines}}{\text{m}} \Rightarrow d = 2.00 \times 10^{-6} \text{ m}$$

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

$$634 \times 10^{-9} = \frac{(2.00 \times 10^{-6}) \sin \theta}{1}$$

$$\sin \theta = 0.317$$

$$\theta = 18.5^\circ$$

Use the following information to answer Q18:

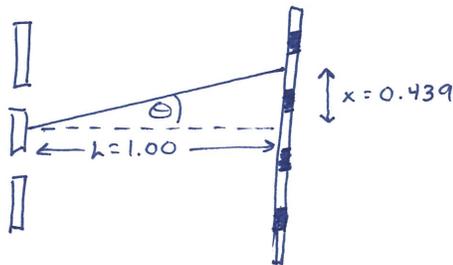
In an investigation, a group of students directs light from a laser pointer at a diffraction grating that has a line spacing of  $1.67 \times 10^{-6}$  m. A series of bright spots appears on a screen placed 1.00 m from the grating. The students measure a distance of 43.9 cm based on the central bright spot and the first order bright spot.

$n=1$

**Q18:** Based on the students' measurements, the wavelength of the light emitted by the laser pointer, expressed in scientific notation, is  $a.bc \times 10^d$  m. The values of  $a$ ,  $b$ ,  $c$ , and  $d$  are \_\_\_\_, \_\_\_\_, \_\_\_\_, and \_\_\_\_.

(Record your **four-digit** answer in the numerical response boxes below.)

6	7	1	7
---	---	---	---



Wrong Method

$$\lambda = \frac{x d}{n L}$$

$$\lambda = \frac{(0.439)(1.67 \times 10^{-6})}{(1)(1)}$$

$$\lambda = 7.33 \times 10^{-7} \text{ m}$$

Can't use this formula because  $\theta > 10^\circ$ .

Correct Method

$$\tan \theta = \frac{x}{L}$$

$$\theta = \tan^{-1} \left( \frac{0.439}{1} \right)$$

$$\theta = 23.701474 \dots^\circ$$

$$\lambda = \frac{d \sin \theta}{n} = \frac{(1.67 \times 10^{-6}) \sin(23.70 \dots)}{1}$$

$$\lambda = 6.71 \times 10^{-7} \text{ m}$$