Name: ______________________________ DISC: ____________ Score: _____ / 20

Instructions:

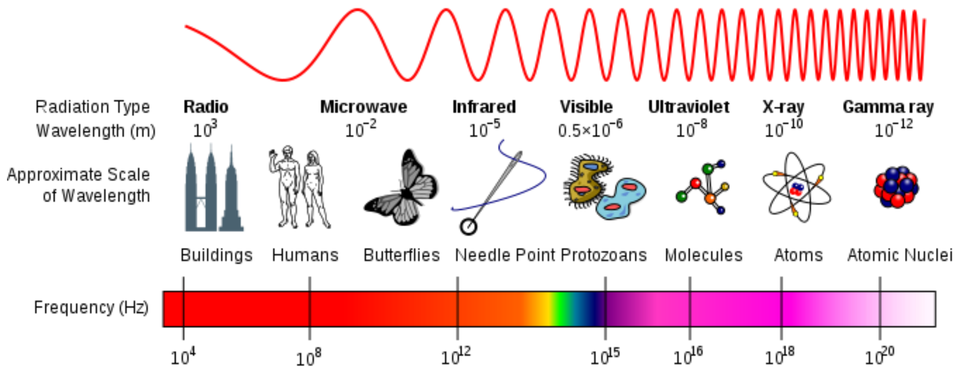
- Do your own work.
- Answer the questions below in the space provided.
- Make sure you show all your work and any equations that you use.
- Please place a box around your answers.
- Remember to give the correct units with all numerical answers

Q1	Q2	Q3	Q4
5	5	5	5

MAGNETIC FLUX	$\Phi = AB\cos\varphi$
EMF ε	$\varepsilon = -\frac{\Delta\Phi}{\Delta t}$
SPEED OF LIGHT	$c = \lambda f$
	$c = \frac{1}{\sqrt{\mu_0\epsilon_0}}$
	$c = 3\times10^8 m/s$
WAVE PROPOGATION	$E = cB$
	$kx - \omega t = 0$ and the same for y and z.
	$k = 2\pi/\lambda$
DOPPLER EFFECT	$f_o = f_e(1+\frac{u}{c})$
	$f_o = f_e(1-\frac{u}{c})$

Useful Information for All Problems

1. Below is a chart for the electromagnetic spectrum.



Frequency (2 pts):

a. If a wave has the same wavelength as a butterfly is long (from wingtip to wingtip) what is the frequency of the wave? Assume your butterfly is 5 cm from wingtip to wingtip.

To solve this question we recall that frequency and wavelength are related to each other through the speed of light: $c = \lambda f$. Looking at the diagram, we would expect a frequency in the 10^9 Hz range. Calculating this explicitly: $f = \frac{c}{\lambda} = \frac{3\times10^8 \, m/s}{0.05 \, m} = 6\times10^9$ Hz (remember, $1\,Hz = 1\,s^{-1}$

b. You have a flashlight which can produce this wavelength of light (the one as long as the butterfly). How fast would the flashlight have to move to shift the wavelength to see the cells on the butterfly's wings. Use the figure above in your estimate.

Doppler Shift (3 pts):

This is a question of the Doppler Effect. Remember the Doppler Effect causes the observer to experience a change in wavelength (or frequency) from the real wavelength.

Step 1: We would like to see the cells on the butterfly's wings. The cells are smaller than the butterfly wing span, so we will need a *shorter wavelength* or *higher frequency* (1 pt for getting this part correct)

Step 2: Use the chart to select a reasonable frequency. Cells are in the visible to near ultra-violet frequency ranges, so $f \approx 10^{15}$ to 10^{16} Hz (1 pt for getting this estimate correct)

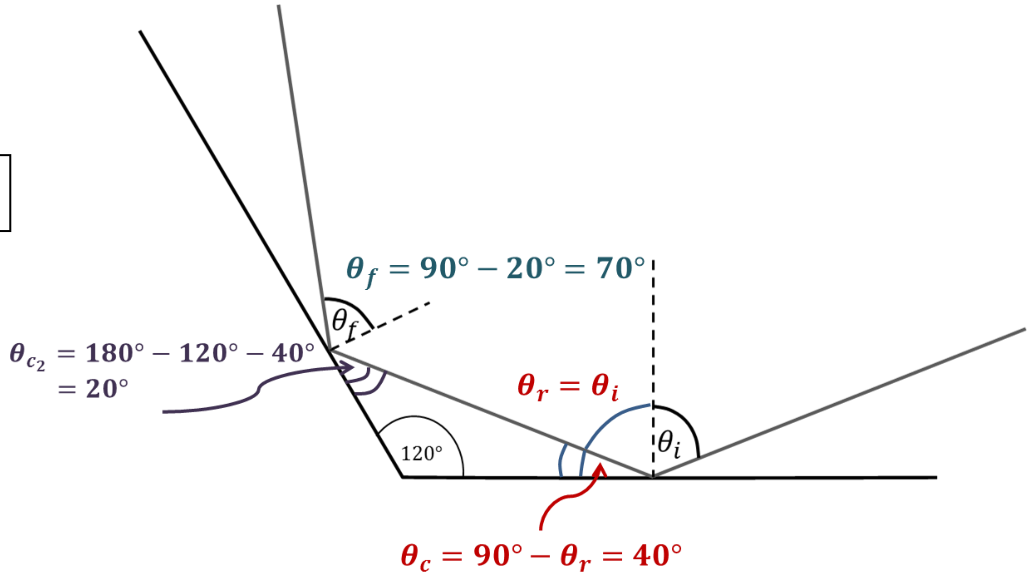
Step 3: Calculate the shift—Using the formula on in the box: $f_o = f_e\left(1+\frac{u}{c}\right)$ <u>(1 point for selecting the correct sign)</u>, where u is the speed we are looking for, and the direction is already taken care of.. Do some algebra: $\left(\frac{f_o}{f_e}-1\right)c = \left(\frac{10^{16}}{6\times10^{9}}-1\right)c = (0.167\times10^{7}-1)(3\times10^{8}) = 5\times10^{14}\ m/s$, which violates all of our physical rules. The speed is greater than the speed of light‼!

Aside:
How could this be? It turns out that light is special. The Doppler shift on the chart is the Doppler shift for low speed (not near the speed of light—like cars) Doppler shifts. What we wanted, however, was a relativistic Doppler shift (you don't need this for the exam).

This very problem was the problem that Einstein was working on when he developed the Theory of Special Relativity (OK, it had to do with clocks, not butterflies, but that's not really the important part). Maxwell and Lorentz who had been working on electrodynamics had observed that the speed of light was a constant, and a consequence of the "Maxwell Equations" which we use to calculate electric and magnetic fields (you don't need to know them for the exam either). This caused a conundrum—what happens as a moving object approaches the speed of light? Using the Classical Doppler Shift, like you did in this question, caused non-physical answers, just like you got! Einstein used observations made by Lorentz to fix this problem. The real Doppler shift looks like: $f_o = \sqrt{\frac{1-u/c}{1+u/c}}\,f_e$ where a negative value for u indicates the source is moving *toward* the receiver.

2. Two mirrors are attached as shown in the diagram. If light reflects from the first mirror with an incident angle $\theta_i = 50°$, at what angle θ_f does it leave the second mirror?

θ_f (5 pts):

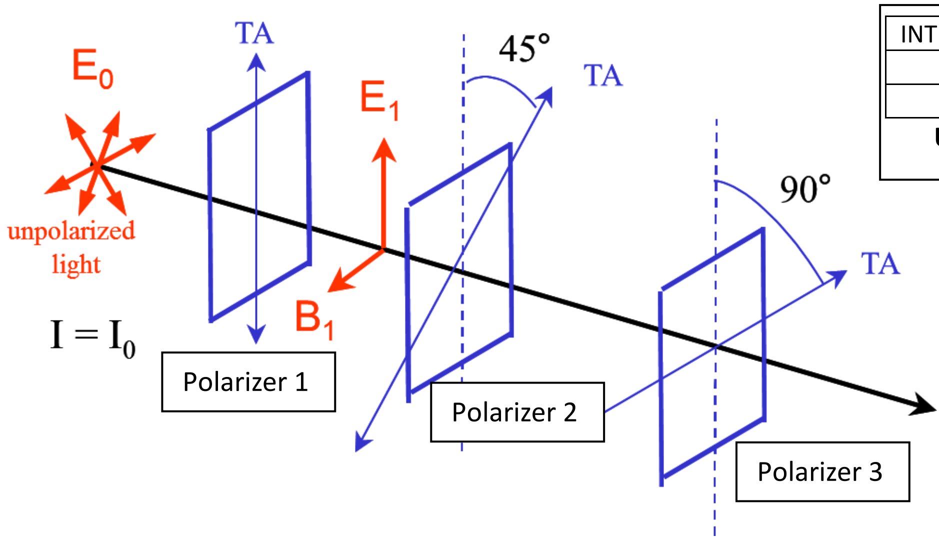


To solve this problem, remember to always measure the angles with respect to the *normal at the point of incidence* (the dashed lines in the diagram.

The first angle is relatively straightforward to calculate. It is shown on the diagram. It is $\theta_c = 40°$
Using the triangle which contains the $120°$ angle we can find the angle of incidence of the second reflection. Recalling that the sum of all angles in a triangle is $180°$, we find the angle with respect to the plane of the mirror of the second reflection is: $180° - 120° - 40° = 20°$

Now $\theta_f = 90° - 20° = 70°$ measured *from the normal to the surface.*

3. Light from an unpolarized source passes through three polarizers as shown below:



INTENSITY	$I_i = I_{i-1}/2$
	$I_i = I_{i-1}\cos^2\theta$

Useful Information for All Problems

Fill in the following table: ***(Show your work on the attach scratch page)***

Table (5 pts):

QUANTITY	Without Polarizer 2	With Polarizer 2
I_1 (after polarizer 1)	$\frac{1}{2}I_0$	$\frac{1}{2}I_0$
I_2(after polarizer 2)		$\frac{1}{4}I_0$
I_3(after polarizer 3)	0	$\frac{1}{8}I_0$

This is a Law of Malus problem. It asks about two different configurations of the these polarizers: 1 with Polarizer 2 between Polarizers 1 & 3, and one without Polarizer 2 between Polarizers 1 & 3.

Step 1: The quantity of light after the first polarizer is independent of the presence of Polarizer 2. Because the incident light is *unpolarized* the intensity of the light *after* polarizer 1 is $I_1 = \frac{1}{2}I_0$

Step 2: Clearly without Polarizer 2 there is no value for "after Polarizer 2" which is why this square is blacked out. With polarizer 2, however, we use the Law of Malus to figure out the intensity after the second polarizer: $I_2 = I_1 cos^2 45^\circ = \frac{1}{2}I_0\frac{1}{2} = \frac{1}{4}I_0$. Remember $\cos 45^\circ = \frac{1}{\sqrt{2}}$

Step 3: Now what happens after Polarizer 3. This will depend on the presence of Polarizer 2.

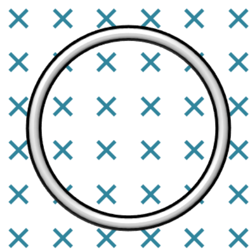
If Polarizer 2 is absent (column 1) the intensity following Polarizer 3 will be zero because the light is vertically polarized after Polarizer 1 and Polarizer 3 has its transmission axis horizontal. Therefore we will have a factor of $\cos^2 90^\circ = 0$.

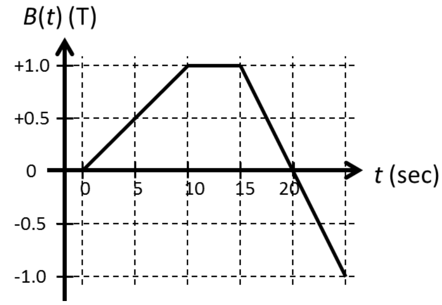
If Polarizer 2 is present the light which as passed through this polarizer is polarized at 45° to the horizontal axis. Thus light *can* pass through the third polarizer, Polarizer 3. Again, apply

the Law of Malus $I_3 = I_2 \cos^2 45^\circ = \frac{1}{4} I_0 \frac{1}{2} = \frac{1}{8} I_0$. Notice 2 things: 1) we used the intensity *after Polarizer 2*; 2) we used the *angle between the polarization direction and the transmission axis* for the angle in the Law of Malus.

4. Consider the wire loop which is located in a time-varying magnetic field, shown in the graph.

Answers (5 pts):





Fill in the following table:

Time(s) at which $\Phi = 0$	$\boldsymbol{t = 0\ s;\ \ t = 20\ s}$
Time(s) at which $\varepsilon = 0$	$\boldsymbol{Between\ t = 10\ s\ and\ t = 15\ s}$
Time(s) at which $\lvert\varepsilon\rvert$ is greatest	$\boldsymbol{Between\ t = 15 s\ and\ t = 25\ s}$
Time(s) at which Φ is greatest	$\boldsymbol{Between\ t = 10\ s\ and\ t = 15\ s}$
Direction of current flow in the loop as seen in the diagram between $t = 0$ and $t = 10\ s$.	***Counter-clockwise***

This is a problem in magnetic induction.

The Flux through the loop is proportional to the magnetic field $\boldsymbol{\Phi = BA}$. The area is fixed in time, but the magnetic field is not. Using the graph on the right, the magnetic field has two times at which it has zero value: $\boldsymbol{t = 0\ s}$ when the field starts and $\boldsymbol{t = 20\ s}$ when it just crosses the time axis.

Remember the EMF $\boldsymbol{\varepsilon = \frac{\Delta\Phi}{\Delta t}}$, or the slope of the flux with respect to time. The times at which the slope of the flux curve are between $\boldsymbol{t = 10\ s}$ and $\boldsymbol{t = 15\ s}$. These are also the same times where $\boldsymbol{\Phi}$ has its maximum value.

The magnitude of the EMF $\boldsymbol{\lvert\varepsilon\rvert}$ is greatest when the slope of the flux curve is greatest. This occurs between $\boldsymbol{t = 15\ s}$ and $\boldsymbol{t = 25\ s}$ using the information in the $\boldsymbol{B\ vs\ t}$ graph.

The direction of current flow through the loop, caused by the varying field is found using the following steps:

1) **The field is pointing into the page**
2) **The field strength is increasing between 0 sand 10 s (i.e. more lines of magnetic field are being produced)**
3) **The induced field will tend to counteract the increasing flux, producing lines of magnetic field which go against the increasing external field.**

4) **Use the right-hand rule to figure out which direction of current will produce *outward pointing* lines of magnetic field—a *counterclockwise* current will produce such field lines.**