Victoria University
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MID Term Assessment

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Answer to the question no 1(a)

Define and write the equation of Coherence, Two Slit/Point Source Interference and Huygen's Principle .

Coherence: A wave is said to be coherent109 if it has a single frequency over a long enough distance (time)) that path difference (time difference) equals phase difference. The coherence time of a wave is the largest such time where this is true, and the coherence length is similarly the largest such path difference, typically c times the coherence time.

• The coherence time τcoh of a typical hot source (such as a light bulb) is anywhere from few tens or hundreds of periods

• The coherence length of a laser can be as long as meters.

Two Slit/Point Source Interference: If one has two coherent, monochromatic sources that are within one another's coherence length (typically very narrow slits that are illuminated by a single source of plane waves) then the intensity received by a distance (compared to slit spacing and wavelength) screen is given by:

$$I(\theta) = 4I_0 \cos2 (\delta/2)$$

where

$$\delta = kd \sin(\theta)$$

is the phase difference between the light waves from the two slits. In this expression, I0 is the central maximum light intensity from either of the two slits/sources alone.

• One can easily find the angles θ where maxima and minima in this interference pattern occur.

Heuristically: The maxima occur where the path difference between the two slits, d sin(θ), equals an integer number of wavelengths (so the light from the two slits/sources arrives at the screen in phase. The minima occur where the path
difference contains a half integral number of wavelengths, so the light arrives at the screen exactly out of phase.

By Inspection or Calculus: By inspection, the maxima in the expression for I(θ) above occur when cos(δ/2) = ±1 and the minima occur when cos(δ/2) = 0. Alternatively, one can differentiate it with respect to δ and set the derivative equal to zero and solve for δ for max's or min's that way. Either path leads one to:

$$d \sin(\theta) = m\lambda \text{ Maxima}$$

$$d \sin(\theta) = (m + 1\ 2\ )\lambda \text{ Minima}$$

with m = 0, ±1, ±2, ±3....

Huygen's Principle: Each point on a wavefront of a propagating harmonic wave acts like a spherical source for the future propagation of the wave. This is the basis of our understanding of interference and diffraction of waves through slits, circular holes, and around other kinds of obstacles.

- ❖ Note well that waves do not travel in straight lines when the pass around or through obstacles or holes through obstacles that are of the same general order of size as the wavelength or less! Waves are perfectly happy travelling around corners (as anyone who has ever watched water waves in a lake or the ocean will attest).

Answer to the question no 1(b)

Proof the equation using Harmonic Waves:

$$I_0 =< |\vec{S}| >_{\text{av}}= \frac{1}{2\mu_0}E_0B_0 = \frac{1}{2\mu_0 c}E_0^2$$

Answer:

Several weeks ago we learned about harmonic waves, solutions to the wave equation of the general form (in one dimension):

E~(x, t) = E0eˆsin(kx − ωt) (1009)

where eˆ is a unit vector in the direction of the wave's polarization. Waves spreading out spherically symmetrically in three dimensions from a source with radius a have a similar form:

E~(r, t) = E0 a r eˆsin(kr − ωt) (1010)

(where |E~(a, t)| = E0 is the field strength at the surface of the source for this component of the polarization). Recall also that we only need to write the electric field strength because the associated magnetic field has an amplitude of B0 = E0/c, is in phase, and is perpendicular to the electric field so that the Poynting vector:

S~ = 1 μ0 E~ × B~ (1011)

points in the direction of propagation. Finally, don't forget that the (time averaged) intensity of the wave is:

I0 =< |S~| >av= 1 2μ0 E0B0 = 1 2μ0c E 2 0 (1012)

We also learned about Huygen's principle, which states that each point on a wavefront of a propagating harmonic wave acts like a spherical source for the future propagation of the wave. This will prove to be a key idea in understanding interference and diffraction of waves that pass through slits, the superposition principle, which says that to find the total field strength at a point in space produced by waves from several sources we simply add the field strengths from all the sources up, and one of the ideas underlying Snell's law, that the wavelength of a wave of a given fixed frequency depends on the index of refraction of the medium through which it propagates according to:

$$\lambda' = \lambda n \quad (1013)$$

where λ is the wavelength in free space; the wavelength of a wave is shorter in a medium with an index of refraction greater than 1 so that the wave slows down. All of these things that we have already learned will be important in our development of interference and diffraction.

In addition to these old concepts, we will require one or two new ones. One is the idea of a hot source. A hot source is something like the hot filament of a light bulb, the hot flame of a candle, the hot gasses on the surface of the sun, all so hot that they glow and give off light. Even the gasses in a relatively cool fluorescent tube are "hot" in the sense we wish to establish, as the atomes that are giving off the light are very weakly correlated with one another.

Answer to the question no 4(a)

 # List the Mobility of Charge in Matter and define them.

Answer:

Mobility of Charge in Matter Matter comes in three distinct forms:

- ❖ Insulators
- ❖ Conductors
- ❖ Semiconductors

• **Insulators :** The charge in the atoms and molecules from which an insulating material is built tends to not be mobile – electrons tend to stick to their associated molecules tightly enough that ordinary electric fields cannot remove them. Surplus charge placed on an insulator tends to remain where you put it. Vacuum is an insulator, as is air, although neither is a perfect insulator. Insulators still respond measurably to an applied field, however – the charges in the atoms or molecules distort as the molecules polarize, and the resulting microscopic dipoles modify the applied field inside the material. Since we live in air (a material) we do not generally see the true electric field produced by a charge but one that is very slightly reduced by the polarization of the air molecules through which the field travels. This is called dielectric response and we'll discuss it extensively later.

• **Conductors.** For many materials, notably metals but also ionic solutions, at least one electron per atom or molecules is only weakly bound to its parent and can easily be pushed from one 38 Week 1: Discrete Charge and the Electrostatic Field molecule to the next by small electric fields. We say that these conduction electrons are free to move in response to applied field and that the material conducts electricity. Conductors also have some special properties when they respond to applied fields beyond this that we'll learn about later. Since electrons are bound to atoms by forces with a finite magnitude, all matter is a conductor in a strong enough field. Dielectric insulators that are placed in such a strong field experience something called dielectric breakdown and shift suddenly from an insulating to a conducting state. Lightning is a spectacular example of dielectric breakdown.

• **Semiconductors**. These are materials that can be shifted between being a conductor or an insulator depending on the potential difference at the interfaces between different "kinds" of semiconducting materials. This is an entirely quantum mechanical effect and his hence a bit beyond the classical bounds of this course, but it certainly doesn't hurt to know that they exist, as semiconductors are extremely important to our society. In particular, semiconductors are used in three critical ways: they are used to make diodes (which we will indeed study when we talk of rectification in AM radios), as amplifiers (transistors) (used to make the music adjustably loud enough to listen to), and as switches from which the digital information processing devices are built that dominate modern existence. This list is far from exhaustive – see Wikipedia: http://www.wikipedia.org/wiki/semiconductors for a more complete discussion.

From this you can see that charge is indeed ubiquitous. We (and everything around us) are made up of charged particles – even the neutral neutrons in the nuclei that make up most of our mass are made up of charged particles. What holds atoms together? What keeps atoms apart? It is time to learn about one of the most important force laws in the Universe, the one that is perhaps most responsible for chemistry and biology.

Answer to the question no 4(b)

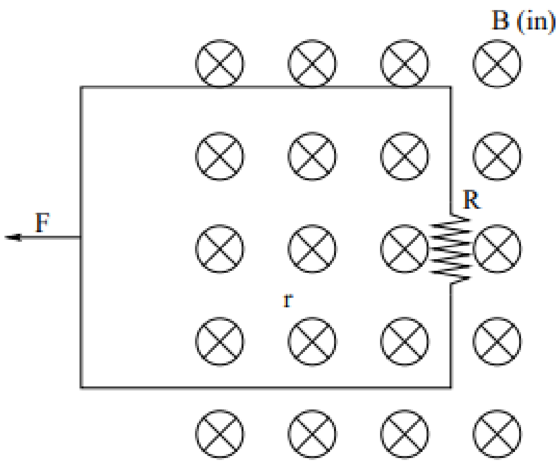
 # Briefly describe about "Rectangular Loop Pulled from Field" with appropriate figure.

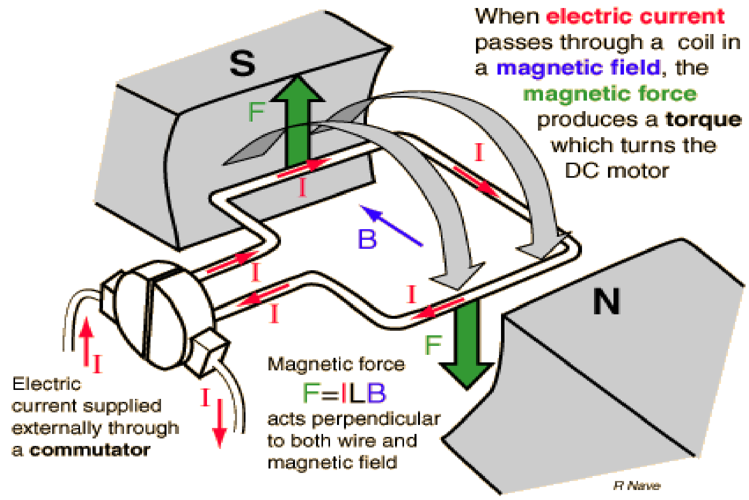
A rectangular loop of wire is pulled out of a region of uniform magnetic field as shown.

In figure 98 you can see a wire loop (rectangular, although this makes no real difference) being pulled from the field. A typical short answer question might show this picture, or a similar picture, of a loop of any shape you like being pushed into or pulled out of a magnetic field and ask you the following questions:

- ❖ What is the direction of the induced E~-field/current in the wire as it is being pulled out (or pushed in)?
- ❖ What is the direction of the magnetic force acting on the loop while this is going on (in either direction)?
- ❖ A trick question might show you the loop completely inside the uniform field (so it isn't actually coming out!) and ask the same questions. What are the answers?
- ❖ When the loop is being pulled out, the flux through the loop is decreasing. The sad little loop doesn't want the flux to go away, so it generates a clockwise current whose magnetic field sustains the disappearing flux.
- ❖ The force on this current (check) resists the motion of the loop out of the field.
- ❖ If the loop were entirely in the field, the flux wouldn't be changing as it moved and there would be no current and no net force.

This example is almost identical to a rod on rails problem, is it not? For a specified geometry and mass m of wire loop and speed v, you might well be able to compute the current, the force, the acceleration, the trajectory.





Answer to the question no 5(a)

 # State the Faraday's Law

In the last section, we saw that for the rod sliding down the rails (at least) we could describe the voltage induced around the closed loop formed by the rails as the time rate of change of the magnetic flux through the loop. We left open the question of how to specify the direction of the induced E-field, although clearly we have to have just the right sign (direction) in order for energy to be conserved as it was for the rod and resistor together.

If we point our right hand's thumb in the direction of the magnetic field through the loop in the previous section and let its fingers curl around the loop the natural direction to specify the "positive" direction for the loop (clockwise as drawn in figure 92), then an increasing loop area and increasing flux produced a negative directed electric field (counterclockwise as drawn) and induced current that went the other way. This in turn made the force on the rod negative as it had to be, it turned out, for energy to be correctly conserved. This suggests that we could have written the voltage that appears in the loop completely consistently with respect to magnitude and direction using this "right hand rule" as:

$$V_{\text{induced in C}} = \oint_C \vec{E} \cdot d\vec{\ell} = -\frac{d}{dt} \int_{S/C} \vec{B} \cdot \hat{n} dA \tag{581}$$

This equation is known as Faraday's Law and is our first truly dynamical field equation for the electromagnetic field. It tells us that changing magnetic flux through an arbitrary loop creates an electric field around the loop. The minus sign on the right hand side tells us the direction of this field – if we let the fingers of our right hand curling around the loop as our thumb points in the (predominant) direction of B~ through the loop, then if the flux through the loop is increasing the E-field circulates the loop C in the negative (right handed) direction; if the flux through the loop is decreasing the E-field circulates around C in the positive direction.

The information encoded in this humble minus sign (which leads to energy conservation) is so important that it has a name of its own – it is called Lenz's Law. Lenz's Law can be stated a different way in words as well:

The electric field induced in a loop by changing magnetic flux goes around the loop in the direction such that any current generated by the field will create a magnetic field of its own that opposes the change in the magnetic flux.

This is a very interesting result, and is worth studying for a moment all by itself before returning to the many applications of Faraday's Law.

First, though, note well that Faraday's Law states that an electric field will be induced around arbitrary loops C, not just loops C that correspond to the position in space of conductors! This is actually consistent with our reasoning in the very first section; we concluded that for the isolated (no conducting loop) rod moving in the magnetic field, it experienced an external electric field from the magnetic field sweeping over it in the frame where the rod is at rest and the field moves in the opposite direction. In fact, even in this problem where there is no loop at all the area swept out by the rod is dA = Lv dt

$$\Delta V_{\text{ind}} = -\frac{dBdA}{dt} = -BLv = -EL \qquad (582)$$

so that the induced electric field is Eind = −Bv (where the minus sign means that the field points in the opposite direction to the "crossed fields" electric field that develops to cancel it).

The existence of the induced electric field in free space even where there are no charges or conductors is key to our later development of the dynamic electromagnetic field – it suggests that the induced E-field can propagate through empty space as long as there is a changing magnetic field present to produce it, even with no charges or conductors locally handy for the field to act on.

Faraday's Law is truly a sublime result. As we will see, this Maxwell Equation is directly responsible for our ability to generate and transmit electrical energy to run our homes, our businesses, our industries, our entertainments, our lives. If it were not for Faraday, I would at best be laboriously typing this textbook on a mechanical typewriter by candlelight and you would not be able to read it until a publisher (at great expense) typeset the entire book and printed it with a steam or water driven press to sell for a small fortune, making its contents available only to the fortunate and the wealthy.

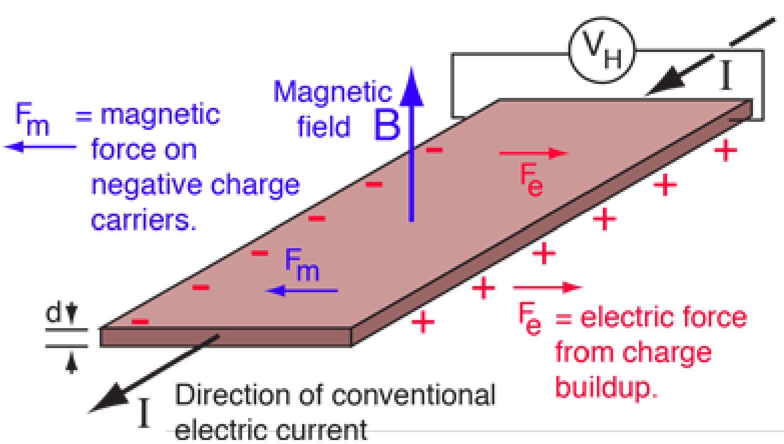
Instead you are very likely reading a purely electronic version of the textbook that you got for free, or perhaps paid a pittance for as a gesture of courtesy to the author72, all thanks to electricity generated via Faraday's Law and transmitted as electromagnetic wave energy and processed in countless ways inside your computer that also rely completely on Faraday's Law. Each and every one of these carefully engineered occurrences is an "experimental test" of Maxwell's Equations in general and Faraday in particular, so you can have a great deal of confidence that it is at the very least a very good approximation to some true underlying principle or law of nature.

In the next section, we will discuss Lenz's Law and give several examples of using it either algebraically or conceptually to determine the direction of the induced electric field around a loop, as promised.

Answer to the question no 5(b)

I) The Hall Effect

Answer:
If an electric current flows through a conductor in a magnetic field, the magnetic field exerts a transverse force on the moving charge carriers which tends to push them to one side of the conductor. This is most evident in a thin flat conductor as illustrated. A buildup of charge at the sides of the conductors will balance this magnetic influence, producing a measurable voltage between the two sides of the conductor. The presence of this measurable transverse voltage is called the Hall effect after
E. H. Hall who discovered it in 1879.
Note that the direction of the current I in the diagram is that of conventional current, so that the motion of electrons is in the opposite direction. That further confuses all the "right-hand rule" manipulations you have to go through to get the direction of the forces.



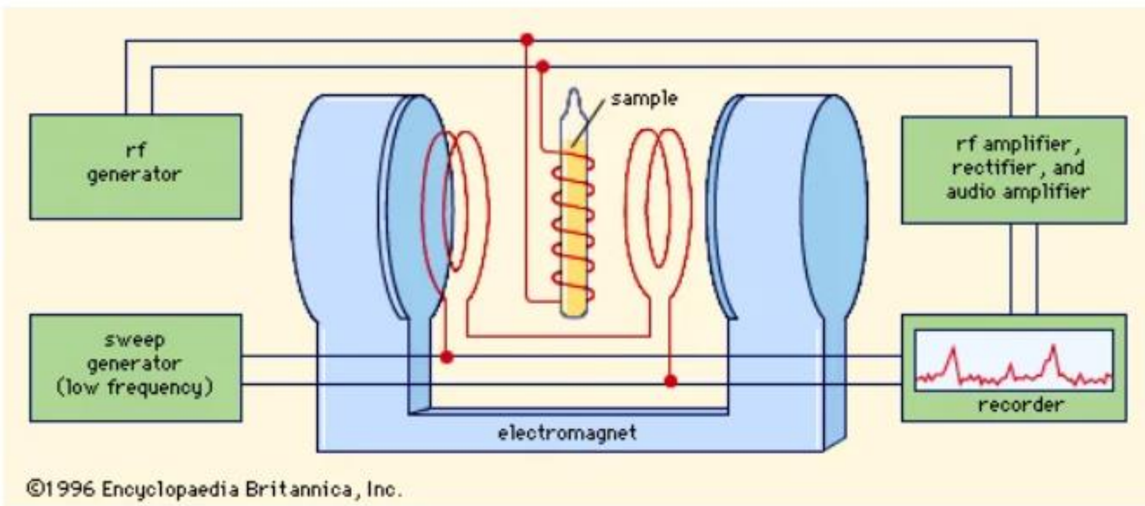
The Hall voltage is given by

$$V_H = IB/ned$$

where n = density of mobile charges and e = electron charge.
The Hall effect can be used to measure magnetic fields with a Hall probe.

III) Magnetic Resonance

magnetic resonance, absorption or emission of electromagnetic radiation by electrons or atomic nuclei in response to the application of certain magnetic fields. The principles of magnetic resonance are applied in the laboratory to analyze the atomic and nuclear properties of matter.



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