Analysis of Experimental Data

1. Significant Figures (Accuracy and Precision)

* No figures should be included beyond the precision of the original data

Ex. $L \neq \underbrace{2.556}_{4\ S.F.} \pm \underbrace{0.034}_{3\ S.F.}$ m or $L \neq \underbrace{2.56}_{3\ \text{digit places}} \pm \underbrace{0.034}_{4\ \text{digit places}}$

take the other # rounded

* rms error should only have ONE significant figure except if 1/2
* As # of significant figures increases, precision increases (the smaller uncertainty) BUT the smaller the % error, and closer to theoretical result, accuracy increases

2. Types of Errors

There a generally two different types of errors:

1) Systematic Errors (due to wrong calibration, wrong construction of instruments, external conditions, observational errors)
   ⇒ eliminate through careful planning

2) Random Errors (no known cause, statistical in nature, large # of independent causes)

3. Error Analysis

A) Measurement (manual/digital)

so for example if measuring values through ruler (several measurements).

You get the final answer and uncertainty through two ways

- ONE measurement

Final Answer = Length $\pm\ \alpha$ → $\frac{\text{smallest subdivision}}{2}$ (manual)

→ smallest subdivision (digital)

Ex. if measure w/ ruler 5.6 cm,
then smallest subdivision is 1 mm = 0.1 cm thus $\alpha = \pm 0.05$ cm

- MULTIPLE measurement

Final Answer (rms) = $\bar{x} \pm \alpha$ → $\alpha = \frac{\sigma}{\sqrt{N}}$ where N is # of readings

how to get it on the calculator:

MODE – (3) STAT – (1) 1-VAR – fill them in – AC – SHIFT – 1 – (4) VAR

2: $\bar{x}$
3: σ
} Replace to get final answer

3) Propagation of Error (rms error)

* used when calculating uncertainty through formula

suppose you have this equation

$PV = nRT$ where you have to find error on P - here is what you do

1) Rearrange equation so you get your characteristic (variable) on one side, and all others on other side

$$P = \frac{nRT}{V}$$

2) To calculate uncertainty, you need two things:

① - error for each variable

② - derivative for your main variable where you assume all others as constant

$P = \frac{nRT}{V}$ has V, R, and T variable

① we should be given $\alpha_V, \alpha_R, \alpha_T$

② $\frac{\partial P}{\partial R} = \frac{nT}{V}$ (as if $P = \frac{nT}{V} R$ like $y = Kx$ so $\frac{dy}{dx} = K$)

$$\frac{\partial P}{\partial T} = \frac{nR}{V}$$

$\frac{\partial P}{\partial V} = -nRT \times \frac{1}{V^2}$ (since if $y = \frac{K}{x}$ then $y' = -\frac{1}{x^2} \times K$)

3) Apply the formula to get error on your main variable

$$\alpha_P = \sqrt{\left(\frac{\partial P}{\partial R}\alpha_R\right)^2 + \left(\frac{\partial P}{\partial T}\alpha_T\right)^2 + \left(\frac{\partial P}{\partial V}\alpha_V\right)^2}$$

Notes:

- if equation has $\sin\theta$ then its $\frac{\partial P}{\partial \theta}$ (no $\partial \sin\theta$)
- if you already got error previously for linear regression, you can follow it through propagation of error

c) Linear Regression

use it to find a linear relationship between two variables

$\boxed{y = Bx + A}$ (always define B: slope of line and A: y-intercept)

First, insert values in calculator (after MODE - (3) STAT - (2) A+BX)

then press AC, shift 1 (stat), 5 (Regression) so chose

1: A (y-intercept) 2: B (slope) 3: r (correlation factor)

$-1 < r < 1$ but if $r > 0$ then +vly corr.
$r < 0$ then -vly corr.
as $|r|$ increases, strength increases

to find the error on the slope, you should follow a series of steps

1) Find x^2 (each value) and the totals / sums of each column
2) Find ei for each value ($e_i = Bx_i + A - y_i$)
3) Find e_i^2 (and sum)
4) Find $\Delta = N \Sigma x^2 - (\Sigma x)^2$

Join them all together in

$$\alpha_B = \sqrt{\frac{N}{N-2} \times \frac{\Sigma e_i^2}{\Delta}}$$

Note: on significant figures, if there is a $\times 10^x$ then you have to put it outside and join for both

Ex. you get $A = 78.352 \times 10^{-5}$ and $\alpha = 0.53 \times 10^{-6}$

FINAL ANSWER $= (78.35 \pm 0.05) \times 10^{-5}$ m

on comparing b/w values or "commenting"

first find [your value $-\alpha$; your value $+\alpha$], but if theoretical doesnt fit

then find [your value -2α; your value $+2\alpha$] and then check if fits

- if it fits, then results are compatible
- if it doesnt fit, then possibly systematic error

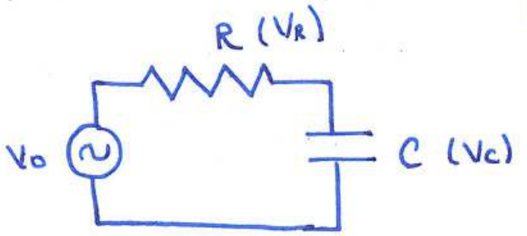
RC and RL circuits

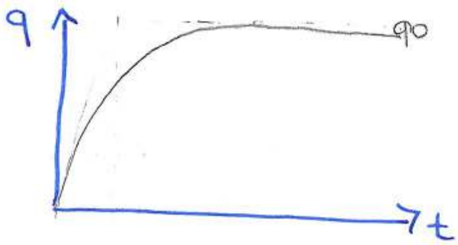
Equipment:

- computer
- PASCO SW 750 Interface → acts as the source of DC voltage
- PASCO RLC circuit board → has resistor, capacitor, and inductor
- digital multi-meter → to measure inductor's resistance
- RLC meter
- connecting wires

Theory

(A) RC circuit





- When a DC voltage is supplied to an uncharged vapacitor in series with resistor, the charge on the plates of capacitor

$$q = \underbrace{CV_0}_{q_0}\left(1 - e^{-t/\tau_c}\right)$$

* As the charge on capacitor increases, it increases exponentially until it reaches a maximum value (asymptotically at $q_0 = CV_0$) during charging

where $\tau_c = RC$ capacitive time cst

- At halftime (the time it takes to charge capacitor to half its final value)

$t_{1/2} = \ln 2 \times \tau$ THUS $\boxed{\tau_c = \frac{t_{1/2}}{\ln 2}}$ (experimentally)

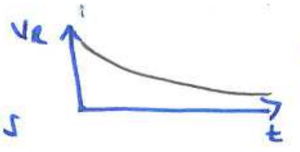
- The charge on capacitor is $\boxed{q = C \times V_c}$ where V_c is voltage across capacitor

- We know that $I = \frac{dq}{dt}$ but $q = C \times V_c$ thus $I = C\frac{dV_c}{dt}$

thus $I = \underbrace{\frac{V_0}{R}}_{I_0} e^{-t/\tau}$ * thus the current can be indirectly measured by measuring $V_R = IR$ (so $I = V_R/R$) due to uniqueness of current

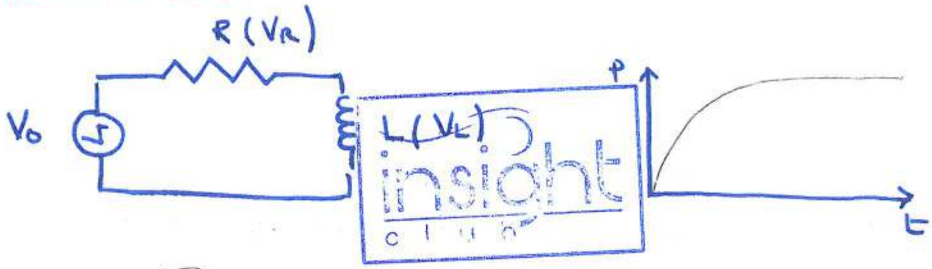
- Equations in terms of voltage across capacitor

$\underbrace{\overset{V_{capacitor}}{V_c} = V_0\left(1 - e^{-t/\tau}\right)}_{\text{because it charges}}$ and $\underbrace{V_R = V_0 e^{-t/\tau}}_{\text{because decharges}}$ $V_{resistor}$



in phase with current (parallels)

(B) R–L circuit



- When a DC voltage V_o is suddenly applied at $(t=0)$ to an inductor L in series with a resistor, R, the current in the circuit is given by

$$I = \underbrace{\frac{V_o}{R+R_L}}_{I_o}\left(1 - e^{-t/\tau_L}\right)$$

* As the current in the circuit increases, it does so from 0 until it reaches the maximum value (asymptote) at $\frac{V_o}{R+R_L}$

where $\boxed{\tau_L = \frac{L}{R+R_L}}$ (inductive time constant)

and the time taken to reach half its final value $t_{1/2}$ is given by

$$t_{1/2} = \tau_L \ln 2 \quad \text{thus} \quad \boxed{\tau_L = \frac{t_{1/2}}{\ln 2}}$$

the voltage across the resistor $V_R = IR$ becomes

$$\boxed{V_R = \frac{V_o R}{R+R_L}\left(1 - e^{-t/\tau_L}\right)}$$

since its in phase w/ current

How to measure the current at each point? (*)

we measure voltage across resistor, and get it indirectly through $\boxed{I = \frac{V_R}{R}}$

the voltage across the inductor $V_L = V_o - V_R$ is given by

$$\boxed{V_L = \frac{V_o R}{R+R_L} e^{-t/\tau_L} + \frac{V_o R_L}{R+R_L}}$$

$\frac{V_o R}{R+R_L} + \frac{V_o R_L}{R+R_L}$

At $t=0$, $V_L = V_o$

At $t > 5\tau$, $V_L = \frac{V_o R_L}{R+R_L}$

Ally

Procedure

(A) Set up connections of RC circuit where 1) you connect output of SW 750 unit to 330F capacitor in series with 100 Ω resistor on PASCO circuit board (while short circuiting inductor) 2) the connect a voltage sensor to Analog input (A) of SW 750 interface. 3) connect the banana plugs of voltage sensor across 330 F capacitor ⇒ to measure Vc w.r.t. time

Procedures

(A) connections for RC circuit

1) connect OUTPUT of SW 750 to 330F capacitor in series with 100 Ω resistor while short-circuiting the inductor (on the PASCO circuit board)

2) connect voltage sensor to analog (A) INPUT of SW 750 unit

3) connect the banana plugs of voltage sensor in parallel w/ 330 F capacitor ⟹ * This enables you to measure V_C as a function of time *

4) connect the banana plugs of voltage sensor (previously connected to analog (B) INPUT of SW 750 unit) across the 100 Ω resistor ⟹ * this enables you to measure V_R as a function of time *

5) After you turn on computer and open document / program, press start - the voltages V_R and V_C will appear automatically on screen

Note: when cursor placed on V or t unit axes it can be used as a stretching tool
when cursor placed on X or Y axes it can be used to drag graph

(B) connections for R

1) Measure resistance of inductor using the multi-meter
2) connect the output of SW 750 unit to the 8.2-mH inductor in series with the 10 Ω resistor (on PASCO circuit board)
3) Connect banana plugs of sensor (A) across the inductor ⟹ * This enables you to measure V_L as a function of time *
4) connect banana plugs of sensor (B) across the resistor ⟹ * this enables you to measure V_R as a function of time *

Measurement of Magnetic Induction Fields

1. Object

The measurement of magnetic induction fields B, produced by a bar magnet, a solenoid, a circular coil, using Hall-effect Teslameter

2. Equipment

- HP- power supply (30V)
- BK- precision power supply
- digital multimeter
- solenoid
- two coils
- bar magnet
- phywe Teslameter
- wooden bench

3. Theory

The magnetic field measurement is based on the $\boxed{\text{Hall effect}}$.
=> the testameter has a Hall element at the tip of the probe, so the meter reads the Hall voltage (which is proportional to the magnetic field) and translates it into magnetic field measurement

* consider a $\boxed{\text{circular coil}}$ consisting of N turns and carrying a current I. The magnetic induction field B at point P on the axis, a distance x from the center of the coil is given by

helmholz

$$\frac{\mu_0 N I R^2}{[R^2+(d/2)^2]^{3/2}}$$

① $$\boxed{B = \frac{\mu_0 N I R^2}{2[R^2+x^2]^{3/2}}}$$

A solenoid is a long wire wound in a closed-pack helix.

* If the $\boxed{\text{solenoid}}$ has a length L and N number of turns of wire, thus by integrating eqn ①, that the magnetic field inside the solenoid carrying current I is

② $$\boxed{B = \frac{\mu_0 N I}{2L}[\cos\theta_1 - \cos\theta_2]}$$

Derivation: *

At the center of solenoid, $\boxed{\cos\theta_2 = \cos(\pi - \theta_1) = -\cos\theta_1}$

so $\cos\theta_1 - \cos\theta_2 = 2\cos\theta_1$ (magnetic field greatest when $\cos\theta_1 - \cos\theta_2$ is maximum)

thus $B = \dfrac{\mu_0 N I}{2L}(2\cos\theta_1) = \dfrac{\mu_0 N I \cos\theta_1}{L}$

$$\cos\theta_1 = \frac{L/2}{\sqrt{L^2/4 + d^2/4}} = \frac{L/2}{1/2\sqrt{L^2+d^2}}$$

thus $\boxed{\cos\theta_1 = \dfrac{L}{\sqrt{L^2+d^2}}}$

inside:
its strong and uniform magnetic field

outside
weak & varying magnetic field

Note :

$$B = \frac{\mu_0 N I R^2}{2[R^2 + x^2]^{3/2}}$$

~~solenoid~~ coil

Part A: Solenoid

Please follow the following steps in performing the experiment:

1. Switch on the Tesla meter (TM) and adjust the digital reading for 0 with the potentiometer knob at the right of the front panel.
2. Measure the length and outer diameter of the solenoid. The outer diameter of the spool onto which the solenoid is wound is 45.0 mm.
3. Install the solenoid on the long wooden bench and connect it in series with the ammeter and the power supply. Turn the fan and the power supply on.
4. Turn the voltage knob completely clock-wise. Adjust the solenoid current to 5 A using the two current knobs.
5. Place the TM probe at the center of its track in the wooden bench. Adjust the position of the solenoid so that the probe-tip is near the center of the solenoid. Make sure that the probe is horizontal. Move the probe in its track to make sure that the probe-tip moves along the axis of the solenoid.
6. Move the TM probe in successive steps of 1 cm along the length of the solenoid. Start with the tip of the probe, at a position of about 4 cm from outside one end of the solenoid until the probe sticks out about 4 cm at the other end. Record the field value at every point.
7. Plot the field values as a function of position and deduce the position of the center of the solenoid.
8. Set the probe at the center of the solenoid and measure the magnetic field, B, as a function of the current, I, in steps of 1 A from 1 to 7 A.
9. Plot B versus I and calculate the slope of the curve using linear regression. Also estimate the uncertainty on the slope.
10. Deduce the number of turns in the coil, N, and its uncertainty using Equation 2.
11. Place the solenoid parallel to the probe so that the tip of the probe is *outside the solenoid* 1 cm from the side near the center. Measure the magnetic field at this position.

Measure outer di
✓ Switch on TM

Measure outer diameter & length of solenoid. Turn on TM and adjust reading to 0. Put solenoid on wooden bench, connect in series w/ ammeter & power
turn on fo

Part B: Coil

Please follow the following steps in performing the experiment:

1. Place the coil in series with the ammeter and the hp power supply. Adjust the current to slightly less than 200 mA.
2. Repeat steps 5 to 7 of Part A except that the TM probe should be moved in successive steps of 2 cm for a total span of 20 cm (10 cm on each side of the coil).
3. Calculate the field at the center of the coil using Equation 1 and compare it to the measured value.

deduce B at center of ~~coil~~ solenoid
determine N from linear

Part C: Bar Magnet

Take the bar magnet and place first one end of it against the probe tip and then the other end. Record both reading of the TM.

current 5A

Measure outer diameter and length of solenoid. Place on wooden bench. connect in series w/ ammeter + power supply. Turn power supply on. Turn volt. knob clockw. Turn TM on and calibrate it (to 0 on potenth.) + adjust so probe tip near center of solenoid move 1cm along length.... plot B as a function of F

Measurement of charge to Mass Ratio of Electrons

1. Purpose

To determine the ratio of the charge to mass of an electron

2. Equipment

* set of Helmholz coils
* cathode-ray tube
* power supply
* ammeter
* voltmeter
* variable resistors
* transformers

3. Theory

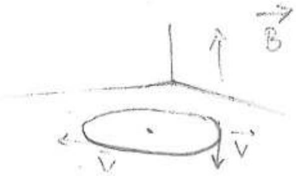
* When a moving electron passes through a magnetic field, it is subjected to a magnetic force

$F_M = evB \sin\alpha$

B: magnetic field
v: velocity of moving electron
e: Charge of electron 1.6×10^{-19} C
α: angle b/w direction of magnetic field and direction of velocity

if the velocity and magnetic field are perpendicular, then the expression of the force becomes

$\boxed{F_M = evB}$ This causes the e^- to move in a circular orbit, the plane of which is perpendicular to magnetic field



* But, although there is no tangential acceleration, there is a centripetal acceleration and its force balances / is in equilibrium w/ magnetic force

$\boxed{F_m = evB = \frac{m}{r}v^2}$ where the radius r of circle is such that the centripetal force caused by magnetic force

and the mass m is mass of e^-

If the electron aquires its velocity by being accelerated through a potential difference V, then (as learnt previously)

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

where V: potential difference
e: charge of the electron

combining the two equations gives us

$$\boxed{\frac{e}{m} = \frac{2V}{B^2 r^2}}$$

using this equation you can determine ratio of e to m if V, B and r are known

4. Description of Set-up:

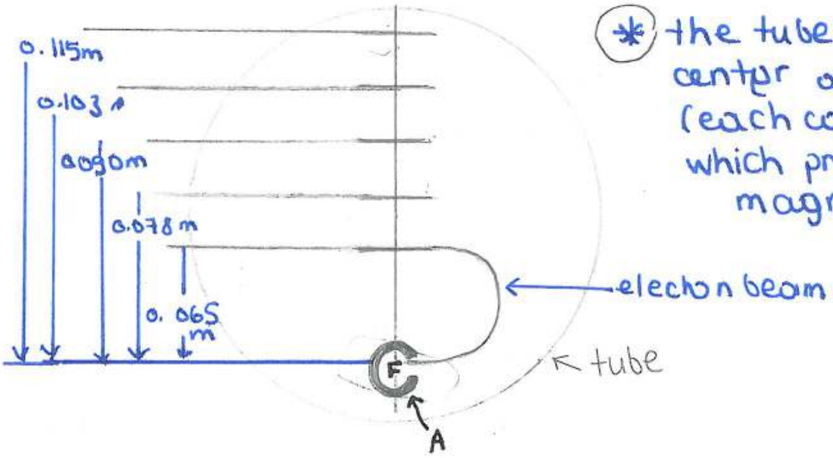
* The principal part of the set-up is an evacuated tube (cathode tube) in which the beam of electrons is produced

* The electron gun is composed of a straight filament wire F along the axis of a cylindrical anode A with a single axial slit S

* Electrons emitted from the heated filament are accelerated by the potential difference V between the filament F and anode A
⇒ part of the electrons come out of the slit as a narrow beam

* the tube contains low pressure mercury (Hg) vapor

If the emitted electrons have sufficient kinetic energy and collide with the mercury atoms in tube, some of these atoms become ionized
⇒ when these ions combine w/ stray electrons (not in beam), the mercury spectrum is emitted w/ its characteristic blue color
∴ the path of these electrons can be made visible



* the tube is placed at the center of the Helmholz coils (each coil has a certain r) which provide a homogeneous magnetic field needed to deflect the e^- in a circular path

* the identical pair of coils consist of N turns (indicated on coil) or radius R (~0.33 m) and carrying a current I.

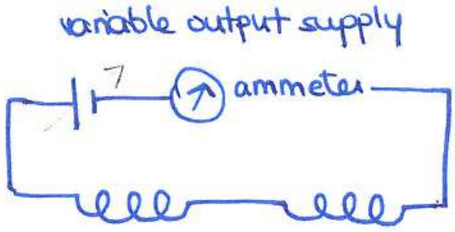
* the magnetic field at the center of the coils on the axis of the coils is given by:

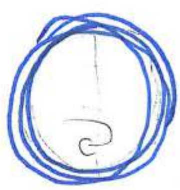
$$B = \frac{\mu_0 N I R^2}{\left[R^2 + \left(\frac{d}{2}\right)^2\right]^{\frac{3}{2}}}$$

where B (magnetic field) expressed in T
d is the separation of the coils
R is the radius of coils
N is the # of turns
$\mu_0 = 4\pi \times 10^{-7}$ (permeability of free space)

* Electrical Circuit of coils:

A power supply connected to the coils such that:





← Helmholz coils wrapped around the tube (so inside is a magnetic field).

* Inside the tube are five metal bars at known distances from the filament ⇒ the distances are the DIAMETERS of various circular orbits which the electron beam follows

* The circuit (w/ certain electrical connections to the cathode ray tube) are mounted inside a metal box

* The filament current is supplied by two transformers, and the circuit current can be controlled through the variable transformer R_1 (the magnitude of current in filament is read by 0-5 ammeter)

* A battery of 45 V supplies the anode voltage → can be controlled by R2, a variable resistor

5. Procedure

1) Measure the value of d and R carefully using a meter stick in more than one position

2) Close switch s_2 and adjust R_2 until the anode voltage meter shows an accelerating voltage of 20–25 V (to accelerate the e^-)

3) Turn R_1 fully counterclockwise, close switch S_2, and adjust R_1 until the anode current meter shows a current of 5–10 mA
⇒ the filament current will then be 3 A

* Observation: the filament would be glowing and electron beam now visible, striking the wall of the tube (beam curved due to B_{earth})

4) Turn on the variable resistor of the Helmholz Coils (fully clockwise) then close the switch and adjust the value of the current until the electron beam is straight and perpendicular to the target rod

=> The magnetic field of the coils is now $\boxed{\text{equal}}$ and $\boxed{\text{opposite}}$
* to the Earths magnetic field

(coils are tilted and oriented so that they are (the field is) parallel, NOT perpendicular, to the magnetic field of the earth

- Record the value of I_1 (repeat to obtain average value)

5) Increase the magnetic field current until the electron beam describes a circle; adjust the current until the sharper edge of beam strikes a crossbar. This is the value of I_2

6) Repeat procedure for each of these crossbars

7) $I = I_2 - I_1$ (used in calculation of magnetic field)

8) Plot $\frac{1}{R^2}$ vs B^2 and determine e/m from slope

Capacitance and Dielectric Constant Measurement

1. object

To measure the capacitance of a number of unknown capacitors, in series and parallel combinations as well as that of a BNC cable to also determine the dielectric constant of a sheet of an unknown material.

2. Equipment

- Digital capacitance meter (LRC meter)
- Capacitance Box
- circular parallel plate capacitor
- Dielectric sheet
- small flat dielectric sheet pieces
- coaxial cables
- BNC connector
- micrometer
- vernier calipers
- ruler
- connecting wires

3. Theory

A capacitor is a device that can store energy in an electrostatic field, and it can be used in a variety of electric circuits

- In its most general configuration, a capacitor consists of two conductors of any shape that are placed near each other without touching
- it is said to be charged when the plates carry opposite and equal charges (+q and -q respectively) which may be done by connecting the two plates to opposite terminals of the battery

If the magnitude of the potential difference between the two plates, upon charging, is V then the capacitance of the capacitor is denoted by C as:

$$\boxed{C = \frac{q}{V}} \quad (1)$$

The value of C is expressed in farad F and solely depends on the * geometry of the device and * the material that fills space

The capacitance of an empty parallel plate capacitor

$$\boxed{C = \frac{\varepsilon_0 A}{d}} \quad (2)$$

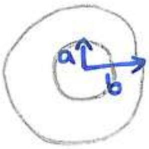
ε_0: permittivity of free space
A: area of the plates
d: separation b/w the plates

If a sheet of dielectric thickness d is inserted b/w two plates, then the capacitance becomes:

$$\boxed{C = K \varepsilon_0 \frac{A}{d}} \quad (3)$$

K: dielectric constant of material of sheet
A: area of plates
d: separation b/w plates (thickness of dielectric)

one can also show that the capacitance of the coaxial cable (consisting of two long coaxial conducting cylinders of radii a and b) is equal to:



$$\boxed{C = 2\pi \times K \times \varepsilon_0 \times \frac{L}{\ln(b/a)}} \quad (4)$$

where L is length of cable, and K is the dielectric cst

Capacitors in series

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \dots \frac{1}{C_n}$$

capacitors in parallel

$$C_{eq} = C_1 + C_2 + \dots C_n$$

4. Procedure

A- unknown capacitors and combinations

1) connect the first of the unknown capacitors cx, to the 'LRC' meter

2) set the range of the LRC meter to obtain the greatest resolution and record the value of the capacitance

Repeat the above steps for the other two unknown capacitors Cy and Cz

3) Read off the nominal values of your capacitors. the tolerance on these values is 10%.

Make the parallel/series combinations and record findings

B- Parallel Plate capacitor

1) Place the three small dielectric sheets/pieces of dielectric sheet at the circumference of the lower disk, then carefully place the top plate on top of it

=> Thus you have a circular parallel plate capacitor w/ air in b/w as a dielectric, and the plate separation $\boxed{\text{EQUAL}}$ to the thickness of the three small pieces (act as stands)

2) Measure as in part A the capacitance of "empty" parallel plate capac

3) Measure using micrometer or vernier caliper the thickness of the three plastic spacer pieces.

4) Using a ruler, measure diameter of plates of capacitor

=> calculate value of capacitance.

Remove the three small pieces and insert the disk of dielectric material in b/w

2) Measure everything like in the previous part and calculate the

e- coaxial cables

1) connect the banana to coaxial adaptor to LRC meter and measure the capacitance of adapter

2) connect the coaxial cables, one at a time, to the adaptor and measure the capacitance of each one of the two coaxial cables (separately)

3) Measure the length of two cables and determine the value of capacitance per unit length of each of the two cables

=> then determine the dielectric cst of material used in cable

4) connect the two cables using a female-female BNC connector, and measure the equivalent capacitance of the combination

Atomic Spectroscopy

1. Object

To measure the wavelength of radiation emitted by different exited atoms, and analyze the hydrogen atom spectrum

2. Equipment

1) $\boxed{\text{Optical Spectrometer}}$ is an optical instrument that breaks light into its component colors

2) $\boxed{\text{Grating}}$ is an optical component that consists of a large number (100+) of parallel, closely spaced slits. It disperses light and produces a spectrum. It diffracts a parallel beam of light by an angle θ (and since θ depends on λ, then ...)

3) gas discharge tubes (Hydrogen, Mercury, Neon)

4) Sodium Lamp and power supplies

3. Theory

* Most light sources emit more than one color of light (wavelengths of more than one wavelength)

* The $\boxed{\text{optical spectrometer}}$ breaks such light into its component colors

* Spectrum: a display of intensities as a function of wavelength

  <u>optical spectroscopy</u> the study of these spectra (wavelengths are characteristic of element emitting light)

* The light emitted by atomic gases in discharge tubes is due to the motion of electrons in the atom

  ⇒ <u>electronic structure</u> determines chemical and physical properties

* Hydrogen atoms give a set of lines in the $\boxed{\text{visible}}$ wavelength region:
  - The line of longest wavelength (lowest frequency) is an intense red line H_α-line then there is the blue-green (H_β-line), the blue (H_γ), the violet H_δ-line
  - Balmer discovered the following experimental relationship b/w wavelengths of this series of hydrogen lines: $\boxed{\frac{1}{\lambda_n} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)}$ (1)

    where $R = 1.096 \times 10^7\ m^{-1}$ (Rydberg's cst)

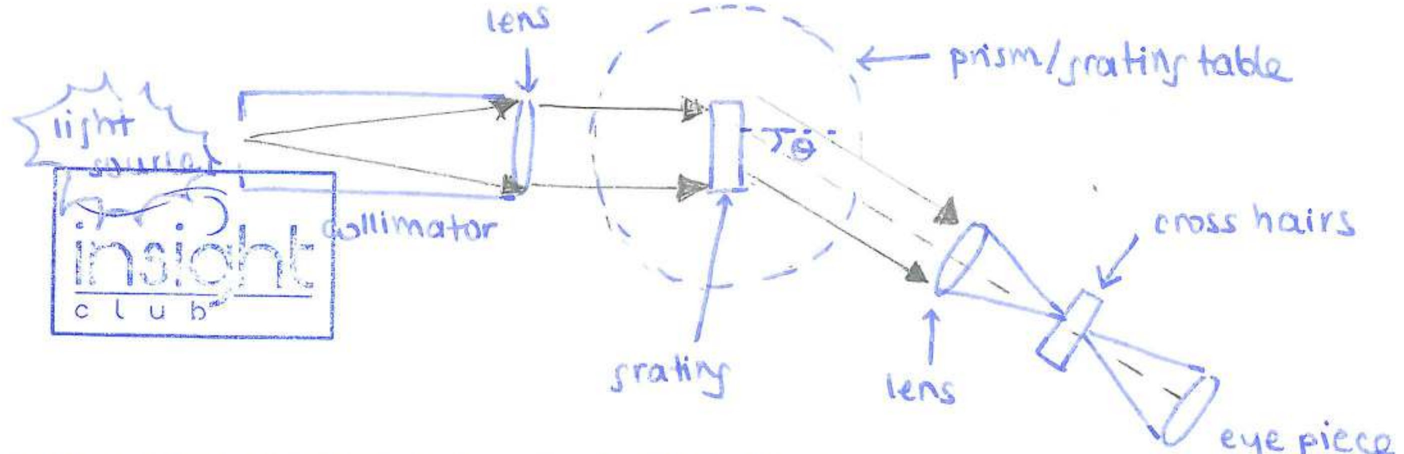
    $n = 3, 4, 5 \ldots$ (integer greater than 2)

* The diffraction grating diffracts a parallel beam of light by angle θ, and the maxima in light intensity (constructive interference) takes place.

The maxima in light intensity takes place according to the following eqn:

(2) $\boxed{n\lambda = d\sin\theta}$ where λ : wavelength of incident light

d : separation b/w two adjacent slits



a) slit is located in focal plane of collimator lens and is illuminated by light source
=> light diverging from slit hits grating in parallel beams from collimator lens

b) This beam of light undergoes a deviation by an angle θ after passing through the prism/grating, and enters the telescope lens

c) An image of the slit is formed on the focal plane of the lens (where crosshairs should be located)

d) The image of the telescope can be rotated relative to axis of collimator (and direction of incident beam) thus θ (angle) can be measured.

=> since θ depends on λ (wavelength) according to eqn 2, thus the
(*) maxima of light intensity will appear at different angles for different colors, and thus grating can be used to break up light into its components

4. Procedure

a- Adjustment of spectrometer

(1) Move the eyepiece lens until the crosshairs are sharp focus

(2) Point the telescope at an object "at infinity" and move lens until focused
=> telescope now adjusted for parallel rays

(3) line up telescope axis w/ collimator axis (w/ grating removed from table)

(4) illuminate the slit and move the collimator lens until a sharp image of slits is seen on the telescop => collimator now adjusted to obtain // rays

(5) Replace the grating on the table, perpendicularly to the axis of the collimator
The spectrometer is ready for use. Do not modify optical adjustments.

b- observation of spectra

(1) Illuminate slit w/ mercury lamp, and describe observation.

(2) Measure θ for each colour (green line) in 1st and second orders, then compare w/ literature value (interval)

(3) Illuminate the slit w/ incandescent lamp. Describe spectrum.

(4) Measure red and violet edges of the spectrum in the first order, and calculate the wavelength range of your visibility.

(5) use hydrogen gas as a light source, and observe/describe spectrum in both first order (n=1) and second order (n=2).

(6) Measure θ for the three lines of H spectrum to left and right of zero pt for both orders

=> Calculate average wavelength from each spectrum line and determine R

Transformers

1. object

To investigate the function of transformers by studying magnetic flux transfer for various configurations of coils and iron core, to demonstrate basic idea of step up /step down transformers

2. Equipment

1/ coils w/ 200, 400, 800, 1600, 3200 turns

2/ Iron cores

3) Function generator

4/ digital multimeters (DMM)

5/ Oscilloscope

6/ Banana wires + BNC cables

3. Theory

- consider two coils in close proximity. If an AC voltage source is connected to the first coil (called primary) then a magnetic field is set up around it. This magnetic field (varying due to AC current) induces a current in the other coil, secondary coil. Thus a magnetic flux also results $N_s \Phi_s$

- The magnetic field in first coil also induces self flux $N_p \Phi_p$

Flux is defined as $\boxed{\Phi = \int B \cdot dA}$ measure of the # of magnetic field lines crossing the coil's area

- The flux through secondary coil depends on flux linkage b/w the two coils (# of lines that leave primary and cross secondary)

so as distance b/w two coils increases, Φ_s decreases rapidly

and if a ferromagnetic material is placed in the external magnetic field since the material has unpaired electrons and permanent magnetic moments, the dipoles align w/ B and medium is magnetized → these dipoles add and enhance the magnetic field

Note: magnetic fields tend to follow the ferromagnetic medium

$V_p = -N_p \left(\frac{d\Phi_p}{dt}\right)$ and $V_s = -N_s\left(\frac{d\Phi_s}{dt}\right)$

if an AC voltage applied to primary coil, it produces a varying magn. field
→ the changing flux through the secondary coil produces an induced emf and an AC voltage

Transformer consists of an iron core (ferromagnetic) to which to coils are wound. An AC voltage applied to 1° coil, thus producing varying magnetic field in the core. Because iron is easily magnetized it enhances the magnetic field compared to an air core, and the magnetic field lines are channeled $\boxed{\text{through}}$ iron core to secondary coil, inducing an emf and AC voltage in 2° coil.

$\Phi_s = \Phi_p$ (all magnetic field lines that exit 1° cross 2°)

$\frac{V_p}{V_s} = \frac{N_p}{N_s}$ if $N_p > N_s$ → step DOWN transformer
if $N_p < N_s$ → step up transformer

(only in a perfectly designed transformer)

THUS the IRON CORE
- → magnetic field lines channeled through iron core to 2° coil w/ no loss
- → enhances the magnetic field (concentrates it in coils)
- → has unpaired electrons and permanent magnet moments
- → easily more magnetized than air
- → ferromagnetic material (easily magnitized)

*If iron core removed, magnetic field is more widespread and transformer is less efficient

* A transformer is a passive device that cannot produce power amplification.
In an ideal transformer, power delivered to primary is equal to power delivered by secondary

$$\left.\begin{aligned} P_{input} &= P_{output} \\ V_p I_p &= V_s I_s \end{aligned}\right] \text{ THUS } \frac{I_p}{I_s} = \frac{N_s}{N_p}$$

4. Procedure

Note ✱ Throughout the experiment, each time you modify configuration of coils, the value of V_p changes. Readjust the value to 1 V using the FG amplitude knob (function generator)

PART I : Transfer of magnetic flux b/w two adjacent coils

1) connect the FG output to one of the 400-turn coils (1° coil) and set the frequency of output signal to 120 Hz, sinusoidal wave

2) connect the output of FG (1° V_p) to CHANNEL 1, and the second coil (secondary V_s) to CHANNEL 2, of oscilloscope.

3) Adjust the MODE and set it to $\boxed{\text{CHOP}}$ → allows you to display the voltages across the two coils simultaneously. set the triggering source to CH1.

4) Adjust, with the AMPLITUDE knob of the FG, the voltage on on 1° coils (V_p) to 1 V (peak to peak) measure

5) Measure and record V_s (peak-to-peak)

6) Repeat measurements . . .

PART II: Magnetic Flux transfer for different coils configuration w/ iron core

Measure and record V_s for the different configurations and position of iron core w/ 400 turn coils. Find the most efficient configuration.

Part III: Step up / step down transformers

a) Voltage Measurements

① Place coils in most efficient configuration
② connect FG to 400-turn coil (primary) as outlined in part I   up it was oscilloscope
③ connect a DMM across each of the coils, and set it to AC volts
④ Turn on FG and adjust the value of V_p to read 1 V. Record V_s
Then measure w/ 400 coil, ... others.

b) Current Measurements

same thing, only connect the DMM of primary coil in series, and set both DMMs to AC amperes. (let $I_p = 10$ mA and readjust for each recording)

c) DC measurement

after putting the two 400 turn coils in most efficient configuration, push the square button lightly on FG so that all buttons are pushed out. now pull the DC OFFSET knob. turn knob fully clockwise (max. amplitude)

→ This is how to turn FG to become a $\boxed{\text{DC powersupply}}$ whose amplitude controlled by the DC offset knob

Connect FG set at a certain frequency across the primary coil of transformer (now in most efficient position, maybe depends on which part of exp). connect each of coils to oscilloscope:

1° coil to channel 1
2° coil to channel 2

adjust MODE to CHOP to be able to track and compare b/w both voltages (simultaneous display)

adjust the voltage of 1° coil to 1 V always using amplitude knob of FG

→ we for diff / measure for combination (u need)

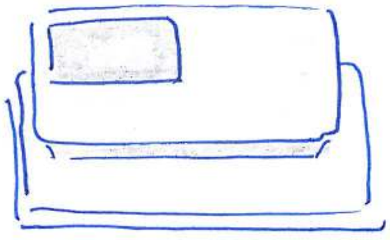
Repeat measurement for different 2° coils

Physics 205

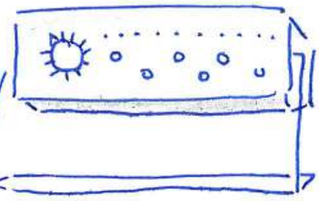
Lab (1) Basic Oscilloscope Operations

theory — controls — operation

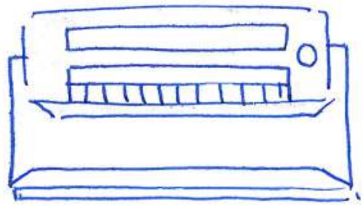
SET-UP *



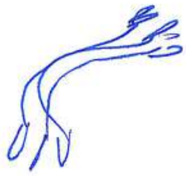
oscilloscope (cathode ray)



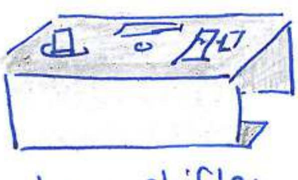
function generator (supplies voltage)



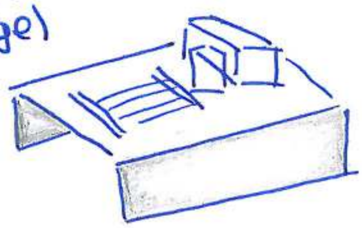
frequency counter (alters frequency)



banana connectors + adaptors



phase shifter (to measure phase diff. b/w two sinosoidal waves)



transformer-rectifier unit (so that

Oscilloscope: electronic instrument that allows (FUNCTION) signal voltages to be viewed (as 2D graph of $\underbrace{\text{voltage}}_{\text{vertical axis}}$ as a function of time / another voltage (horizontal axis))

(+ any other quantity that can be converted to a voltage)

Modern / Digital oscilloscopes
- LED / LCD screens

Cathode Ray / Analog oscilloscope
- $\boxed{\text{cathode ray tube}}$ as display
- simplest type

(0 to 0 ≈ ... LOOK AT FIGURE

Cathode Ray Tube
- evacuated glass envelope
- covered with phosphor flat surface
- has an electron gun: small heated metal cylinder (flat end coated w/ e^- emitting oxides)
- b/w gun and screen there are two opposed pairs of metal plates (deflection plates)
  - vertical → generated vertical potential difference
  - horizontal → generate horizontal voltage

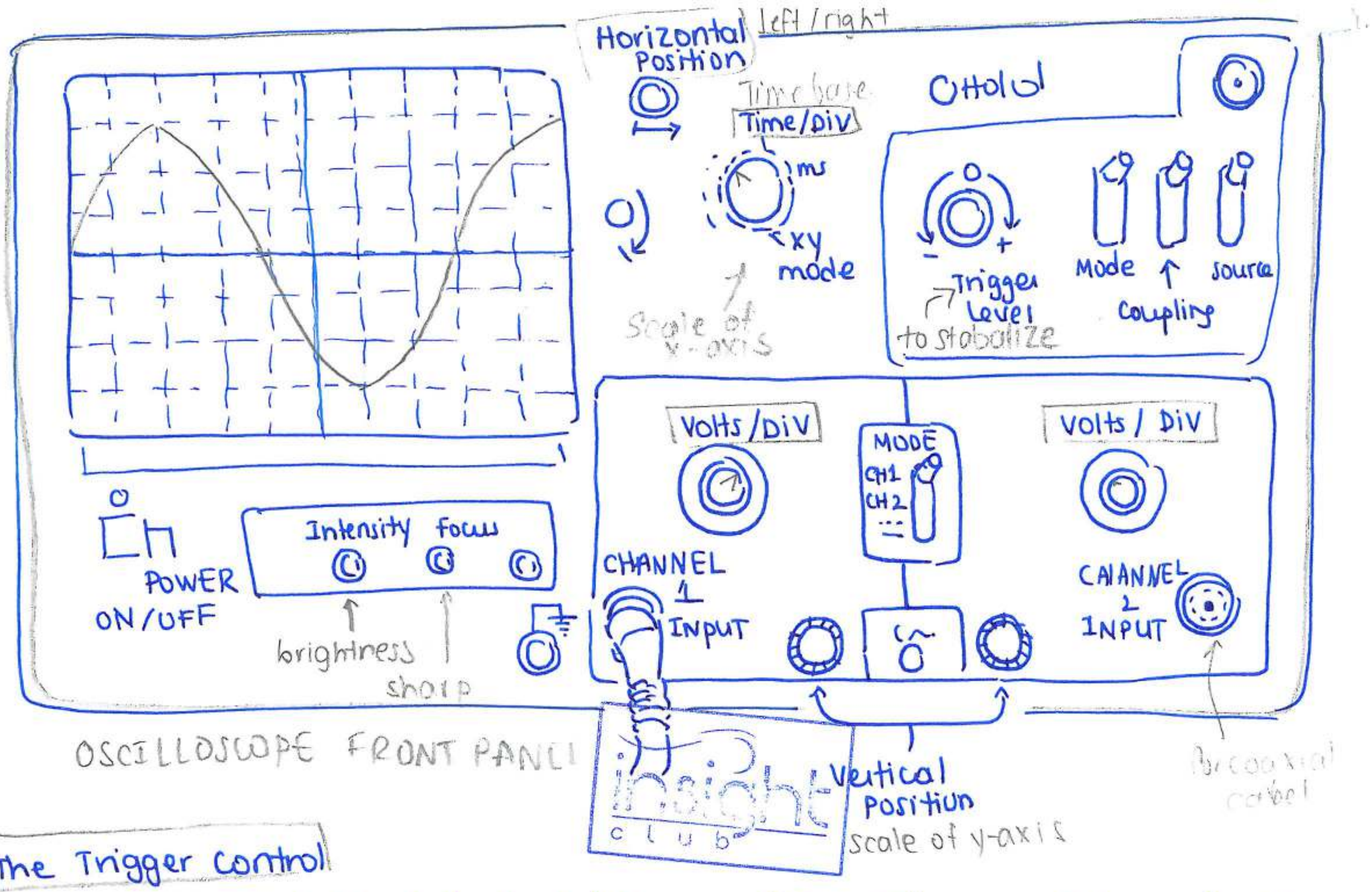
creates an electric field b/w $\boxed{\text{plates}}$ causing spot to deflect

+ve voltage: usually upward deflect

−ve voltage: when field reversed downward deflect

driven by external voltage

(horizontal amplifier does similar job and it either deflects beam to right or to the left)



The Trigger control

Function : a set of controls that determine when each sweep of beam begins
⇒ stabalizes display / trace
① synchronizes the oscilloscope display
② ensures that sweep begins at same pt in repeating image

Why is there unstable trace?
- While beam sweeps from left to right, it does not always start at the same point on input voltage
- The beam might appear as multiple traces jumping on screen

(+/-) function: phase shift by (π)
① triggers upward slope when its in IN position
② triggers downward slope when its in OUT position

How to prepare the oscilloscope!

1. Turn ON the oscilloscope
2. Turn the INTEN control clockwise until you reach the minimum intensity setting that produces a comfortable trace (brightness)
3. Adjust the FOCUS control for a sharp trace
4. Turn the CH1 VERTICAL POSITION control to move the CH1 trace to the centre horizontal line on the screen
5. Turn the HORIZONTAL POSITION control to align the left edge of the trace with the left-most line on the screen.

How to set it up for amplitude measurements:

1. connect output of function generator to CH1 INPUT
2. switch function generator on 500Hz frequency
3. set VOLTS/DIV for a signal as vertically large as possible
4. set TIME/DIV for display as 2-3 cycles shown

Frequency Measurements

1. connect frequency counter to $\boxed{\text{SYNC}}$ output of function generator
2. Read the frequency of the output of function generator on the frequency counter

How to set it up for frequency measurements:

1. set the TIME/DIV control so that CRT displays 2-3 cycles
2. T(period) = sh x x (# of divisions)

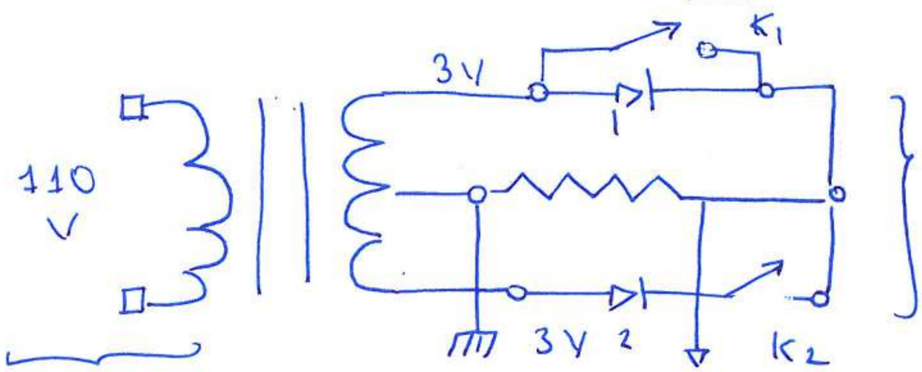
Wave-form Studies : Transformer Rectifier

The transformer rectifier unit consists of
- a transformer
- two diodes → in 1 direction only

Function: rectification – conducts current

Function: transform AC voltage of main powerlines to a 6V sine wave voltage

There are two switches
- K_1 (switched out/in circuit)
- K_2 (switched in/out circuit)



2 sine waves are π rd out of phase
⇓
different waveforms obtained depending on whether K_1, K_2 are opened/closed

transformer rectifier unit is connected to CH1

How to explain waveforms

K_1 open & K_2 closed

upperline

lower line

superposition

on screen of oscillo

K_1 opened: diode 1 allows the current to pass in one direction and blocks it in other direction

short circuit/no current p...

K_2 closed: diode 2 allows the current to pass in one direction and blocks it in other direction

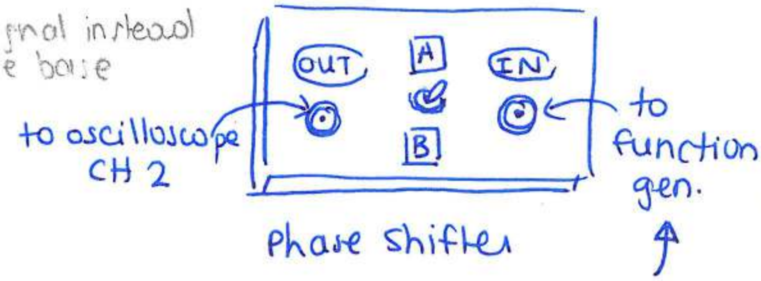
⇒ the lower and upper lines are π rd out of phase

The obtained waveform is a superposition of both waveforms

To measure phase shift b/w two signals

* oscilloscope set at X-Y mode (input signal instead of time base)

* two positions A and B correspond to different shifts



to measure phase difference b/w two sinusoidal waves

(on $\boxed{\text{Ch 1}}$ wave 1, on $\boxed{\text{Ch. 2}}$ wave 2)
measure phase difference

Note: called X-Y mode because both X and Y axes used to trace voltages (not time)

PHASE SHIFT

same period and amplitude (straight line / circle / ellipse)

$$x = B\sin\omega t \qquad \text{so} \qquad x/B = \sin\omega t$$
$$y = A\sin(\omega t + \varphi) \qquad\qquad y/A = \sin(\omega t + \varphi)$$

The following equation obtained:

$$\frac{y^2}{(A\sin\varphi)^2} + \frac{x^2}{(B\sin\varphi)^2} - \frac{2xy\cos\varphi}{AB\sin^2\varphi} = 1 \quad \text{(rotated ellipse)}$$

$\sin^2\varphi + \cos^2\varphi = 1$
$\sin(A+B) = \sin A\cos B + \sin B\cos A$

$$\frac{\phi}{2\pi} = \frac{dt}{T}$$ (# of div)

$\boxed{\text{Eqn 1:}}$ $x = B\sin\omega t$ so $\frac{x}{B} = \sin\omega t$

$\boxed{\text{Eqn 2:}}$ $y = A\sin(\omega t + \varphi)$ so $\frac{y}{A} = \sin\omega t + \varphi$

step 1: expand equation 2

$$\frac{y}{A} = \sin\omega t\cos\varphi + \sin\varphi\cos\omega t$$

step 2: replace by equation 1 $\left(\frac{x}{B} = \sin\omega t\right)$

$$\frac{y}{A} = \frac{x}{B}\cos\varphi + \sin\varphi\cos\omega t$$

step 3: replace $\cos\omega t$ by $\sqrt{1-\frac{x^2}{B^2}}$ (since $\cos^2\omega t + \sin^2\omega t = 1$)

$$\frac{y}{A} = \frac{x}{B}\cos\varphi + \sin\varphi\sqrt{1-\frac{x^2}{B^2}}$$

step 4: Multiply both sides by A

$$y - \frac{A}{B}x\cos\varphi = A\sin\varphi\sqrt{1-\frac{x^2}{B^2}}$$

step 5: Square both sides

$$y^2 - 2\frac{A}{B}xy\cos\varphi + \frac{A^2}{B^2}x^2\cos^2\varphi = A^2\sin^2\varphi\left(1-\frac{x^2}{B^2}\right)$$

step 6: Divide by $A^2\sin^2\varphi$

$$\frac{y^2}{A^2\sin^2\varphi} - \frac{2xy\cos\varphi}{AB\sin^2\varphi} + \frac{x^2}{B^2}\frac{\cos^2\varphi}{\sin^2\varphi} = 1 - \frac{x^2}{B^2}$$

step 7: Rearrange x^2/B^2

$$\frac{x^2}{B^2} + \frac{x^2}{B^2}\frac{\cos^2\varphi}{\sin^2\varphi} - \frac{2xy\cos\varphi}{AB\sin^2\varphi} + \frac{y^2}{A^2\sin^2\varphi} = 1$$

step 8: common denominator

$$\frac{x^2\sin^2\varphi + x^2\cos^2\varphi}{B^2\sin^2\varphi} - \frac{2xy\cos\varphi}{AB\sin^2\varphi} + \frac{y^2}{A^2\sin^2\varphi} = 1$$

THUS $\boxed{\dfrac{X^2}{B^2\sin^2\varphi} + \dfrac{Y^2}{A^2\sin^2\varphi} - \dfrac{2XY\cos\varphi}{AB\sin^2\varphi} = 1}$

$$\frac{X^2}{B^2} + \frac{Y^2}{A^2} - \frac{2XY\cos\varphi}{AB} = \sin^2\varphi$$

For $\varphi = 0^\circ$, $\cos\varphi = 1$ and $\sin\varphi = 0$

thus $\dfrac{X^2}{B^2} + \dfrac{Y^2}{A^2} - \dfrac{2XY}{AB} = 0$

$\left(\dfrac{X}{B} - \dfrac{Y}{A}\right)^2 = 0$ THUS $\dfrac{X}{B} = \dfrac{Y}{A}$ and $y = \dfrac{A}{B}x$ eqn of straight line

For $\varphi = 90^\circ$, $\cos\varphi = 0$ and $\sin\varphi = 1$

$\dfrac{X^2}{B^2} + \dfrac{Y^2}{A^2} = 1$ this is eqn of an ellipse

BUT if $A = B$ then $x^2 + y^2 = A^2 = B^2$
eqn of circle

Another method

$\dfrac{X}{B} = \sin\omega t$ and $\dfrac{Y}{A} = \sin \omega t + \varphi$ but $\sin\omega t + \varphi =$
$\sin\omega t\cos\varphi + \sin\varphi\cos\omega t$

but/ and $\cos^2\omega t + \sin^2\varphi t = 1$

thus $\cos\omega t = \sqrt{1 - \dfrac{X^2}{B}}$

thus $\dfrac{Y}{A} = \dfrac{X}{B}\cos\varphi + \sin\varphi\sqrt{1 - \dfrac{X^2}{B^2}}$

$\dfrac{Y}{A} - \dfrac{X}{B}\cos\varphi = \sin\varphi\sqrt{1 - \dfrac{X^2}{B^2}}$ square both sides then divide by $\sin^2\varphi$

$\dfrac{Y^2}{A^2\sin^2\varphi} + \dfrac{X^2}{B^2\sin^2\varphi} - \dfrac{2XY}{AB}\dfrac{\cos\varphi}{\sin^2\varphi} = 1$ or $\dfrac{Y^2}{A^2} + \dfrac{X^2}{B^2} - \dfrac{2XY\cos\varphi}{AB} = \sin^2\varphi$