brief into to admin aspects of course—
- grading
- structure
- work load (MSE rule of thumb—3 hours outside to 1 inch for B to A grade)
- channels of communication
- handouts

* stress/math expertise is critical
- will have simple diagnostics to indicate when you might need refreshing.
- you cannot be fumbling about with the math (save 10 minutes end)

--- for your intellectual edification---

* historical timeline—
- classical era (~900 BC to ~1900)
  fundamental laws discovered
  - modern era (~last century to 2005)
    applications of electromagnetics

- classical EM
  ~900BC // shepherd in then Greece named Magnus
  - discovered iron nails in sandals pulled to black rock on which he was standing
  - rock later named "magnetite"

~600BC // Thales describes how amber rubbed with cat fur can pick up feather (static electricity)
Classical EM (until)

~ 1000  Magnets discovered, used as navigational aid

1600  William Gilbert (Engl.) coins term "electric" after Greek word for amber (elektron)

1733  Charles-François du Fay (French) discovered electri charges are of 2 types, like charges repel, unlike attract

1745  Pieter van Musschenbroek (Dutch) invented the Leyden jar — 1st electrical capacitor

1752  Benjamin Franklin (US) lightning rod — lightning is electricity

1785  Charles-Augustin de Coulomb (French) discovered elec force between 2 charges is proportional to inverse of (distance)^2 between

\[ F = \frac{kq_1q_2}{r^2} \]

1800  Alessandro Volta (Italian) invents 1st elec. battery

1820  Hans Christian Orsted (Danish) shows interconnection between elec. & mag.

discovered elec. current changes direction of compass needle (orients needle ± wire)

1820  Andre-Marie Ampere (French) discovered parallel currents in wires attract whereas opposite currents repel.
1820 - Jean Baptiste Biot and Felix Savart (Fr) develop Biot-Savart law which relates mag. field due to a wire to the current flowing thru it

1827 - Georg Simon Ohm (Germany) formulates V = IR from exp. observations. Joseph Henry (US) introduces concept of inductance & builds one of 1st elec. motors

1831 - Michael Faraday (Eng) discovers changing mag. flux induces an electromotive force (voltage)

1835 - Carl Friedrich Gauss (German) relates elec. flux thru enclosed inf. to the enclosed electric charge.

1873 - James Clerk Maxwell (Scot) treatise relating elec & mag thru 4 math eqns

1887 - Heinrich Hertz (German) builds system to generate & detect EM waves (at radio frequencies) & discovers "phot voltaic effect"

1888 - Nikola Tesla (Croatia) invents AC motor

1895 - Wilhelm Roentgen (Ger) discovers X-rays (Nobel Prize 1901)

1897 - J J Thomson (Eng) discovers "electron" (Nobel Prize 1906)

1905 - Albert Einstein (German/US) explains photovoltaic effect (Nobel prize in phys 1921)
"Modern EM " telecommunications

1837 - Samuel Morse (US) patents the telegraph
1872 - Thomas Edison (US) patents elec. typewriter
later - the "light bulb"
1876 - Alexander Graham Bell (Scot/US) invents telephone
1887 - Heinrich Hertz (German) demos "radio waves"
show they have same properties as light
1896 - Gugliemo Marconi (Italian)
patents wireless transmission by radio
(Nobel pr. in Phys - 1909)
1897 - Karl Braun (Ger.) invents CRT (Nobel pr. 1909)
1906 - Reginald Fessenden (US) invent AM radio
1912 - Lee De Forest (US) invents triode amplifier
for wireless telegraphy
1919 - Edwin Armstrong (US) invents superhetodyne
type radio receivers (1932 invent FM)
1923 - Vladimir Zvaygzn (US) invents TV
1935 - Robert Watson (Scot) invents radar
1947 - Shockley, Brattain, Bardeen (US) invent transistor
1955 - Narinder Kapany (US/Indian Ames) demos
optical fiber as a light transmission medium
1958 - Jack Kilby / Robert Noyce (US) 1ST IC
1969 - ARPANET - precursor to internet (developed by DoD)
Modern EM - Comp. Technol.

1945 - John Mauchly & J. Presper Eckert develop ENIAC
(1st elec. computer - in US Army)

1950 - Yoshio Nakama (Japan) patent floppy disk

1971 - TI introduces "pocket" calculators
Ted Hoff (US) invents INTEL 4004 - 1st microprocessor

1989 - Tim Berners Lee (Engl) invents WWW

1997 - Palm Pilot becomes widely available (Jeff Hawkins)

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Dimensions, units, notation -

Important for getting "Real Numbers" -

International System of Units (Systeme International)

Important since elec. may come by different routes - and so had diff. units for same quantity

- length
  - meters
  - M

- mass
  - kilogram
  - kg

- time
  - second
  - s

- elec. current
  - ampere
  - A

- temp.
  - kelvin
  - K

- amount of substance
  - mole
  - mol

 Scalars, vector quantities:

  - Scalars = magnitude only; may and directs
  - Vectors \( \vec{E} \) in book bold \( \mathbf{E} \); unit vectors \( \hat{e} \)

  \[ \vec{E} = \hat{e} \times E \text{ (scalar)} \]
we will make liberal use of "phasor" representations in dealing with time varying quantities - a phasor will be represented as \( \hat{E} \)

Nature of EM III

essentially 4 fundamental forces

1. nuclear force (submicroscopic) - strongest subatomic systems holds together

2. EM force - strength \( \sim 10^{-2} \) nuclear force (submicroscopic systems) < between charged particles

3. weak interaction force - strength \( \sim 10^{-5} \) nuclear force (interact in weak radioactive particles)

4. gravitational force - weakest of all \( \sim 10^{-31} \) nuclear force (macroscopic systems)

much theo work done to develop theory to unify all 4 forces - not there yet (Einstein) - unified "field" theory

these forces can be represented by a concept called a "force field"

we will be interested in this made in Force #2 =

note: 1. mainly its macroscopic manifestation in this course
To understand EM force interactions, we need to understand **force fields** (learned a bit in your physics class).

Let us use gravity as an analogy (for starters).

**Newton** (1671)

- Unit of force = **newton**

\[
\vec{F}_{g_{21}} = - R_{12} \frac{G M_1 M_2}{R^2}
\]

- Varies INVERSELY with separation
- Proportional to the masses
- \( - \) means an "attracting" force
- Only one kind of mass

Grav force on M2 due to M1 = \( F_{g_{21}} \)

Means M2 pulled towards M1.

**we can draw a gravitational force field**

IE a force in space due to some mass which would interact with some other mass if it were there.

IE M1 induces a "force" everywhere in space.

**we define this force as a "force field"**

\[
\vec{F}_{g} = - R \frac{G M_1}{R^2}
\]

IE a force/unit mass

If I put \( M_2 \) at \( R \), I get force \( F_{g_{21}} \) defined before.
Important principle here — holds for all linear "fields"

**Principle of Superposition**

Total gravitational field due to a system of masses is the vector sum (linear superposition) of the gravitational fields due to the individual masses.

This is true for "All Force Fields".

\[ \vec{\Psi} = \sum \vec{\Psi}_i \]

Example:

\[ \vec{R} = \vec{R}_{p1} + \vec{R}_{p2} \]

\[ \text{eg } R_x = R_{p1x} + R_{p2x} \]
\[ R_y = R_{p1y} + R_{p2y} \]
Now let's extend to the force we will be dealing in this unit — EM forces

\[ \vec{F}_e = \text{elec force}, \quad \vec{F}_m = \text{mag force} \]

For grav field → source is "mass"
For elec field → source is "electric charge"

Electric field behaves with dist just like grav field (inverse square law)

\[ F_e \propto \frac{1}{R^2} \]

difference is \( M_1 = M_2 \geq 0 \)

But elec charge \( \pm Q \) can be \( +Q - \)

Thus, \[ \vec{F}_{e_1} = \frac{Q_1 Q_2}{R_{12}^2} \frac{\hat{R}_{12}}{R_{12}} \]

\( \hat{R}_{12} \)

\( Q_1, Q_2 \) same sign — force is repulsive
\( Q_1, Q_2 \) opp. sign — force is attractive

(like gravity)

Note: diff materials have diff. "susceptibles"

\[ E = \epsilon_0 \epsilon_r \] relative permittivity

Here, the unit of proportionality is \( \frac{1}{\mu_0} \) in vacuum

where \( \epsilon_0 = \text{permittivity of free space} = 8.854 \times 10^{-12} \text{ Farads/m} \)

charge unit = \( e = 1.6 \times 10^{-19} \) coulombs (magnitude of charge on electron)

\[ q_e = -e, \quad q_p = +e \]
\[ \mathbf{F}_{21} = \frac{1}{4\pi \varepsilon_0} \frac{\mathbf{R}_{12} \mathbf{Q}_1 \mathbf{Q}_2}{R_{12}^2} \quad \text{where } R_{12} = |\mathbf{R}_{12}| \]

In a similar vein as for gravitational fields.

there is an "electric force field" which exists in space due to a charge \( \mathbf{Q}_1 \)

\[ \mathbf{E}_1 = \frac{1}{4\pi \varepsilon_0} \frac{\mathbf{R} \mathbf{Q}_1}{R_1^2} \quad \text{volts/m} \]

force/unit positive charge \( \mathbf{Q}_1 \)

At point \( \mathbf{R}_1 \) force on a unit + charge at a dist. of \( \mathbf{R}_1 \)

the "electric field" obeys some superposition principle as in "grav field"

\[ \mathbf{E} = \sum \mathbf{E}_a \]

important

or \( \mathbf{E} = \int \mathbf{dE} \) for continuous charge distributions

\[ \mathbf{E} = \mathbf{E}_0 \]

summary\\ electric force rules

1. 2 like \( q \) repel; 2 unlike \( q \) attract
2. Force along line between charges
3. Force magnitude \( \propto \frac{\mathbf{Q}_1 \mathbf{Q}_2}{R_{12}^2} \)
4. Coulomb's law \( \mathbf{F}_{21} = \frac{\mathbf{R}_{12} \mathbf{Q}_1 \mathbf{Q}_2}{4\pi \varepsilon_0 R_{12}^2} \)

5. \( \mathbf{E} = \mathbf{E}_0 \)
6. Conservation of charge \( \pm \) cannot create or destroy charge
Now let us discuss magnetic forces, $\mathbf{F}_m$ and the equiv. magnetic force "fields"

we noted earlier that as early as 800 BC the Greeks discovered certain stones (called magnetite) had properties that attracted pieces of iron-

3 then abt 800 yrs later Frederick discovered that these stones would alter "direction" of an compass needle.

by mapping directions of the needle with respect to the stone it was determined that the force lines (dualines) pointed from 2 pts diametrically opposite to mean area. these "poles" N & S existed for every magnet irrespective of size or shape.

In addition, it was observed that like poles repelled one another unlike poles attracted!

so it was thought to speak of "magnetic" charges-

However, one important difference existed-

- elec charge can exist in isolation (ie a single charge)

this will turn out to be one of the 4 fundamental laws of EM

- magn. poles only come in pairs

- to this day, no one has found the existence of a MAGNETIC MONPOLE!
just as with electric fields and fields, we can talk about a magnetic field
we call this \( \mathbf{B} \) the magnetic flux density
it is unrelated to electricity in that we can show it is due to a current in wire.

- Oersted (19th century) showed I could cause a compass needle to deflect.
- Biot Savart showed that the force field resulting from this I was

\[
\mathbf{B} = \frac{\hat{z} \cdot \phi I}{2\pi R} \text{ radial field from wire}
\]

\[
B \propto \frac{I}{R} \text{ in direction tangent to circle surrounding current}
\]

[Rule of thumb: thumb in direction of \( \mathbf{I} \) fingers curl in direction of \( \mathbf{B} \)

what we will see lately is that the velocity of light in free space \( C \)

\[
C = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \text{ in m/s} = 3 \times 10^8 \text{ m/s}
\]

Thus, completely tying together electricity and magnetism.
note: when we have there E&M force fields
in material we need to use the
material permittivity $\varepsilon = \varepsilon_r \varepsilon_0$ rel permittivity
and " permeability $\mu = \mu_r \mu_0$ rel permeability
we will see later that in general, it is useful to
define 2 diff "field" quantities when talking abt materials

electric $\vec{D} = \varepsilon \vec{E}$ (in C/m²) the electric
magnetic $\vec{B} = \mu \vec{H}$ mag flux density

summary $\begin{cases} \vec{E} = \text{elec field intensity} \\ \vec{D} = \text{elec flux density} \\ \vec{B} = \text{mag flux density} \\ \vec{H} = \text{mag field intensity} \end{cases}$

there are the 4 fundamental quanta of E&M
and their interrelations form the fundamental
basis of the 4 fundamental EM laws
called "Maxwell's Equs"

so far we have only discussed forces & fields
that are not changing with time/
Maxwell's eqns include time varying forces
It is convenient to divide up an electromagnetic into static $E_3M$ (i.e., forces don't vary with time) and dynamic (forces vary with time).

What Maxwell showed was that a time-varying electric field generates magnetic fields and time-varying magnetic fields generate electric fields. This implied a new general statement: Maxwell Equations. As an anchor, we will discuss in detail throughout the course—based on these 4 fundamental equations:

- **Gauss's Law**: $\nabla \cdot D = \rho$, the volume charge density.
  - Existence of isolated electric charges.
- **Faraday's Law**: $\nabla \times E = -\frac{\partial B}{\partial t}$
  - No magnetic monopoles.
- **Ampère's Law**: $\nabla \times H = J + \frac{\partial D}{\partial t}$
  - Current density (amps/m²).

In materials, we have electric and magnetic properties characterized by $E_I$, permittivity, and $\mu$, permeability, and a $\sigma$ parameter, called conductivity which characterizes how much electric currents can move.