9942031340
Santhosh@eee.sastra.edu
Santhosh@eee.sastra.ac.in

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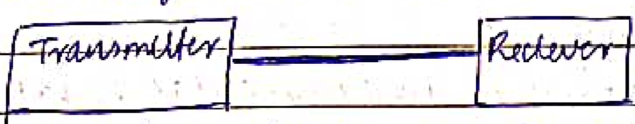
PRINCIPLES OF ELECTRICAL ENGINEERING

- Gilbert William – Magnets
  ↓
  Stephen Grey – Fundamentals & idea of static electricity.
  ↓
  Wheatstone Bridge – came the idea of Telegraph to transfer information. (1st message related to a murder in London)
  ↓
  Samuel Morse – Morse code invention
  (1st message – What hath God wrought)
  ↓
  War of currents – DC & AC → Edison & Tesla.
  George Westinghouse, Chicago light house
- Radio Engineering
  ↓
  WW2
  ↓
  Transistors

UNIT 1

ITRODUCTION TO ELECTRICAL ENGINEERING

- Problems with long range wireless power transmission is that objects inbetween inhibits and the intensity of beam might reduce over time

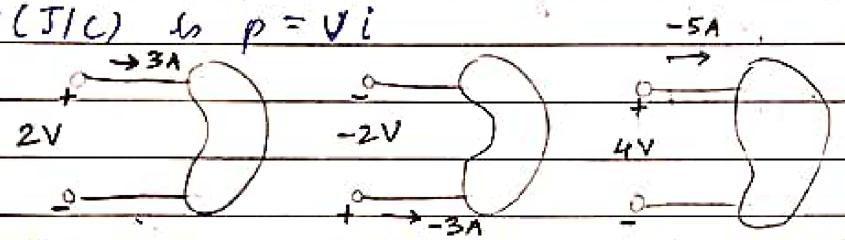


- non-ionising radiation can be used to overcome this problem

- current flows i.e. charge flows only if there is a potential difference
- charge is conserved - neither created nor destroyed
- 1 ampere = 1 coulomb / second (1A or 1C/s)

- Voltage (V) (unit volt) is the potential difference across 2 terminals in a circuit "across variable".
- In order to move a charge from A → B, work needs to be done
- More the potential difference, more the current
  USA - single phase - 110V - 60Hz
  India - single phase - 230V, 50Hz

- The power req to push a current i into a voltage V (J/C) is $p = Vi$

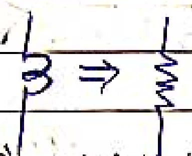


$2 \times 3 = 6W$ — absorbs power
$-2 \times -3 = 6W$ — absorbs power
$-5 \times 4 = -20W$ — supplying energy

$\boxed{\begin{array}{l}\text{Power is +ve} \Rightarrow \text{absorbing energy} \\ \text{Power is -ve} \Rightarrow \text{supplying energy}\end{array}}$

- Resistance (Linear circuit abstraction)

Ex:



→ Material
→ Structure
→ Environment

"Digital twins"

- Idea of considering the element just with the electrical property and leaving out all the other material, structural or environmental related properties is "Linear circuit abstraction." aka "Lumped circuit abstraction"

- $I \propto V$ (provided temperature is constant)

  Using G as constant of proportionality;

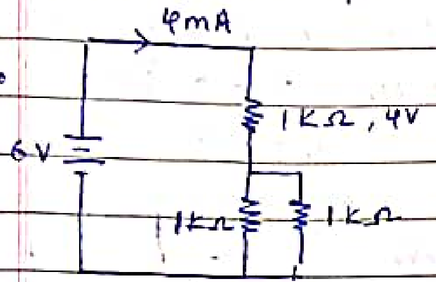
$$\boxed{\begin{aligned} I &= GV \\ V &= IR \end{aligned}}$$

$$\boxed{R = \frac{1}{G}}$$

G − conductance − mho ℧

BBROY

- Other examples of variable resistors are thermistors, potentiometer; photoresistors

- 

$\boxed{R_{total} = 1.5\,k\Omega}$

Voltmeter − very high impedance
Ammeter − very low impedance

fixed capacitor | polarised capacitor | variable capacitor

[Capacitor variations]

Some types of capacitors are:

⇒ Ceramic capacitors
- non polarised
- smol, cheap
- poor temp stability & poor accuracy.
- ceramic dielectric
- used for bypass, coupling

⇒ Electrolytic capacitor
- Al, tantalum electrolyte.
- Tan > Al [Capacitance]
- mostly polarised
- Capacitance ↑ leakage ↑
- Bad temp stability

Axial lead | Radial lead

NOTE: • Capacitors store E in electrostatic form.
• Inductors store E in electromagnetic form.

[Inductor Variations:]

- Chokes:
  - gen purpose inductors that act to limit or suppress fluctuating current.
- Torroidal coil:
  - high inductance per volume ratios, high quality factor self shielding, can be used for very high frequencies also.

☆ Open and short circuit:

(open)
- An open circuit between A and B means $i = 0$
  Voltage across an open circuit : any value
  Resistance $R = \infty \, \Omega$

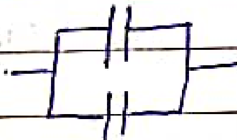
(short)
- A short circuit between A & B means $V = 0$
  current through a short circuit - any value
  Resistance $R = 0 \, \Omega$

Intercontinental data transfer are mostly wired.
Fundamental linear passive elements → L, R, C
Fundamental linear active elements →

☆ Resistors

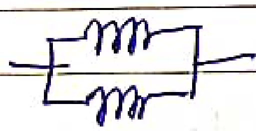
$\boxed{R_s = R_1 + R_2}$ $\boxed{R_P = \frac{R_1 R_2}{R_1 + R_2}}$

Capacitors



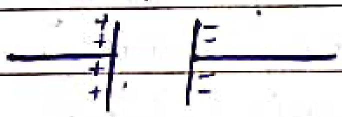
(store DC) (stores energy in the form of electrostatic) $\boxed{C_S = \frac{C_1 C_2}{C_1 + C_2}}$ $\boxed{C_P = C_1 + C_2}$

Inductors



(stores in the form of electromagnetic)

☆ Capacitors:



$\boxed{E = \frac{1}{2} C V^2}$ $\boxed{C = \frac{Q}{V}}$

→ Usage of capacitors ~~as~~ an energy storage device is limited by 2 things:
→ Rate of charge & discharge is very high
→ Capacity of holding charge is low (C)

→ Capacity can be solved by using supercapacitors and ultracapacitors that hold charge using adsorption. 1F, .. , 50F available (1.3V)

Open circuit :

$\boxed{i = 0}$ $\boxed{R = \infty\ \Omega}$

$\boxed{V = \text{any value}}$

Short circuit :

$\boxed{V = 0}$ $\boxed{R = 0\ \Omega}$

$\boxed{i = \text{any value}}$

☆ "Lumped circuit abstraction"

While modelling an electrical appliance, only part specific quatities are considered (like R)

Ex: A bulb is aproximated as a resistance

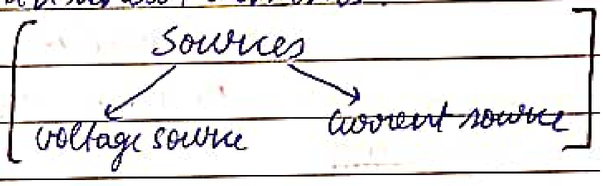
These aproximations might give eronious results but the magnitude of error is quite small.

⇒ A linear circuit element has a liner voltage-current relationship. i.e.:

- if $i(t)$ produces $v(t)$, then $K i(t)$ produces $K v(t)$
- if $i_1(t) \rightarrow v_1(t)$ & $i_2(t) \rightarrow v_2(t) \Rightarrow i_1(t)+i_2(t) \rightarrow v_1(t)+v_2(t)$

• resistors and some sources are linear elements.

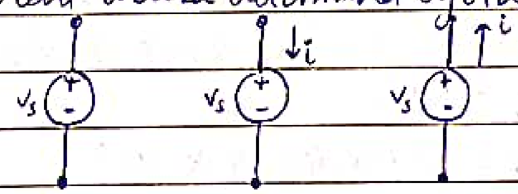
- linear circuit is only with linear elements.



☆ Voltage sources

• A ideal voltage source is a circuit element that will maintain the specific voltage V_s across ~~ad~~ its terminals.

• The current will be determined by other circuit elements



• For domestic consumers 230 ± 6 % variation is allowed.

• A devices with ISO certification can hande 15 % variation (or) with a stabiliser.

☆ Current sources:

• An ideal current source is a circuit element that maintains the specified current flow is thrgh its terminals.

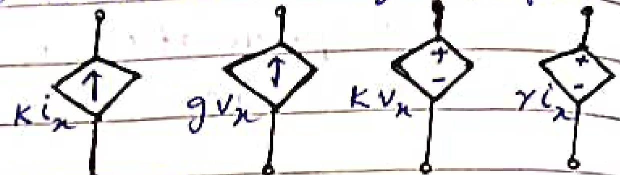
• Voltage source with a series inductor can be considered a current source.

• Voltage is determined by other circuit elements.

* DEPENDANT & INDEPENDANT SOURCES:

* Dependant sources:

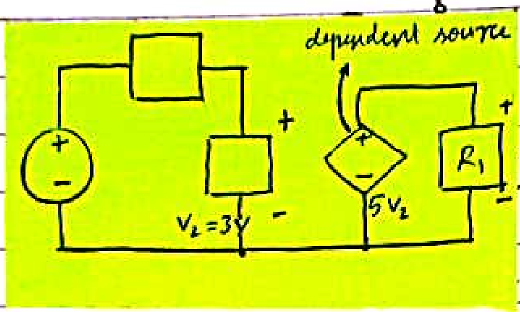
Dependent sources ① and ② maintain a current specified by another circuit variable.
Dependent sources ③ & ④ maintain a voltage specified by another circuit variable.



EX: Solar panel

Ex:

(KVL)
$5V_L - V_L = 0$
$V_L = 5V_L$



$5V_2$ is the dependant source

$V_L = 5V_2$ (parallel)

$V_L = 5 \times 3$

$\boxed{V_L = 15V}$ //

Ohms law-resistors:

Linear resistor obeys ohms law. $\boxed{v = iR}$

Resistors absorb power.

$$\boxed{p = vi = v^2/R = i^2R}$$

lowercase - instantaneous
upper case - steady state

Power is always +ve for a resistor (ie) absorbing power.

QUE: 560 Ω resistor is connected to a circuit which causes a $i = 42.4$ mA to flow. $V = ?$ $P = ?$

$V = iR$

$V = 560 \times 42.4 \times 10^{-2}$

$V = 56 \times 424 \times 10^{-2}$

$V = 237.44V$ //

$P = V^2/R = iR^2$

$P = (237.44)^2 / 560$

$P = 100.674 W$ //

◇ dependant

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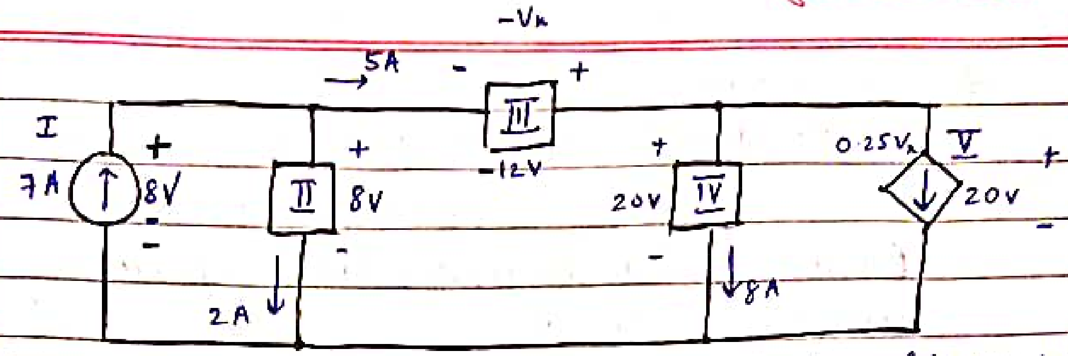
QUE:



(supplier) I ⇒ 8×7 = 56 W

(dissipate) II ⇒ 8×2 = 16 W

(supplier) III ⇒ -5×12 = 60 W

IV ⇒ 20×8 = 160 W (dissipate)

V ⇒ 20×V_x/4 = 20×0.25 V_x
= 20×0.25×12
= 60 W [dependant source]
(dissipate)

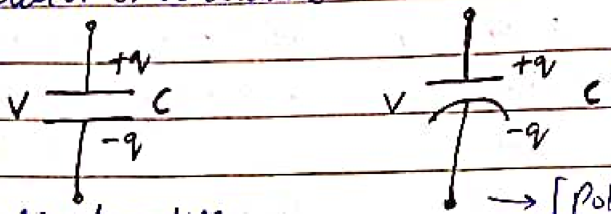
$\boxed{\begin{array}{l} i \text{ towards } +ve \Rightarrow \text{supplier} \\ i \text{ towards } -ve \Rightarrow \text{dissipator} \end{array}}$

Loads
- → Charger / gadgets - DC
- → Light - DC
- → TV - DC
- → Refrigerator - DC
- → Fans - AC/DC
- → UPS - DC
- → AC - DC
- → Washing machine - DC
- → Motors - AC

• ≈ 70% of loads are DC in nature
• AC signals can't be stored and DC power or signals can be. Thus AC should be converted to DC for storage

Capacitors and Inductors are also linear elements like Resistors but unlike R, these can only store energy, which can be retrieved later. Energy is not dissipated in C and L

★ Capacitors:

- Passive element that stores E in its electric field in the form of electrostatic energy.
- Consists of 2 conducting plates seperated by an insulator or dielectric
- 

[fixed polarity; terminals cant be interchanged]

→ [Polarised capacitor]

longer lead — +ve
shorter lead — -ve

$$\boxed{q = Cv}$$

[can store DC electricity]

- C – capacitance of capacitor. measured in Farads (F)
- Capacitance is the ratio of the charge on one plate of a capacitor to the voltage diff between the two plates, measured in Faradds (F)

  1F = 1 coulomb / 1 volt
- C depends on surface area of plates and the dist between the plates & permittivity of material

- $q = Cv$

  $\frac{dq}{dt} = C\frac{dv(t)}{dt} = i(t)$ $\qquad \left[v(t_0) = \frac{q(t_0)}{C}\right]$

  $v(t) = \frac{1}{C}\int_{-\infty}^{t} i(x)\,dx = \frac{1}{C}\int_{-\infty}^{t_0} i(x)\,dx + \frac{1}{C}\int_{t_0}^{t} i(x)\,dx$

  $v(t) = v(t_0) + \frac{1}{C}\int_{t_0}^{t} i(x)\,dx$

- Instantaneous power delivered ⇒

  $$\boxed{p(t) = vi = Cv\frac{dv}{dt}} = \frac{q^2}{2C}(t)$$

  $W = \int p(t)\,dt = C\int dv \times v$

  $$\boxed{W = \frac{1}{2}Cv^2(t)\ J}$$ (energy stored)

$CV^2 = C \times \frac{q^2}{C^2}$

- Capacitor should not be connected directly to a source mostly since it tries to take max V from source and may lead to dangerous amt of current being lost. Might damage battery electrodes.

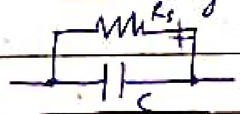
Capacitors properties:

- When voltage across C is constant, then i

$$i = C\frac{dV}{dt} = 0$$

Thus a capacitor is an open circuit to DC. BUT, if a DC source is suddenly connected, C charges.

- Voltage across capacitor must be continuous since a sudden jump change in V would require an infinite current (impossible).
  Capacitor thus resists abrupt change in V.
  "Voltage across capacitor can't change continuously"
  BUT current can change.
- Ideal capacitor does not dissipate energy
- Non ideal (real) cap has a "leakage resistance" which can be as high as 100 MΩ and is neglected.

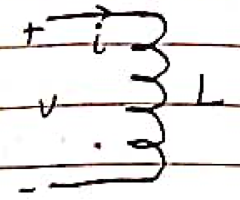


$\boxed{C_p = C_1 + C_2 + \cdots + C_K}$, $\boxed{\frac{1}{C_S} = \frac{1}{C_1} + \cdots + \frac{1}{C_K}}$

$(i = i_1 + i_2 + \cdots + i_K)$ $(V = V_1 + V_2 + \cdots + V_K)$

☆ Inductors:

- Passive element - stores E in the form of electromagnetic energy.
- Consists of a coil of conducting wire wound around core.
- $$\boxed{v(t) = L\frac{di(t)}{dt}}$$



L - Inductance - Henry (H)

- 1H = 1 volt second / ampre
- Inductance - property whereby an inductor exhibits opposition to the change of current flowing through it.

[Capacitor opposes sudden change in voltage
Inductor opposes sudden change in current]

(energy stored in the magnetic field)

$$\boxed{w_L(t) = \frac{1}{2}Li^2(t)\,J}$$

$$v(t) = L\frac{di(t)}{dt}$$

(instantaneous power)

$$\boxed{p(t) = vi = Li\frac{di}{dt}}$$

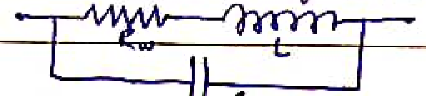
$$i(t) = \frac{1}{L}\int_{-\infty}^{t} v(\lambda)\,d\lambda \qquad i(-\infty) = 0$$

$$\boxed{i(t) = i(t_0) + \frac{1}{L}\int_{t_0}^{t} v(\lambda)\,d\lambda}$$

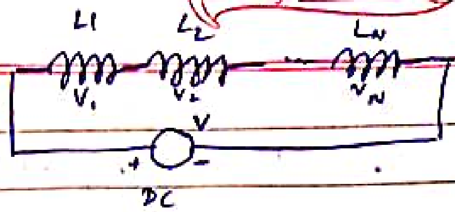
Inductor properties

- Inductor acts like a short circuit to DC
  $$v(t) = L\frac{di(t)}{dt} \qquad \left[\begin{array}{l} V = 0 \text{ when} \\ i = \text{a constant} \end{array}\right]$$
- The current through an inductor can't change instantaneously, since an instantaneous change in current would require ∞ V.
- Ideal inductor does not dissipate energy
- Real inductor has significant R due to resistance of coil as well as "winding capacitance".

⇒



Series inductor :



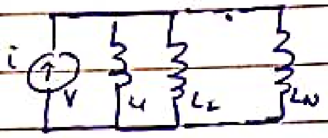
$V = V_1 + V_2 + \cdots + V_N$

$= (L_1 + L_2 + \cdots + L_N) \frac{di}{dt}$

$= L_{eq} \frac{di}{dt}$

$$\boxed{L_{eq} = \sum_{k=1}^{N} L_K}$$

Parallel inductor :



$i = i_1 + i_2 + \cdots + i_N$

$= \left(\frac{1}{L_1} + \frac{1}{L_2} + \cdots + \frac{1}{L_N}\right) \int v\,dt = \frac{1}{L_{eq}} \int v\,dt$

$$\boxed{\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} + \cdots + \frac{1}{L_N}} \boxed{= \sum_{k=1}^{N} \frac{1}{L_K}}$$

Inductor – opposes sudden change in current
Capacitor – opposes sudden change in voltage

* WORK , POWER , ENERGY :

Generation   Captive power plant
↓
Transmission
↓
Distribution → LT – Low tension
             → HT – High tension

The consumers of power make up whats known as a Grid

- Every large-scale power system has 3 major components
  - Generation : source of power, ideally with a specified voltage and frequency.
  - Load / demand : consumes power, const R
  - transmission system : transmits power , conductor

  [Additional components]
  - Distribution system : local recirculation of power
  - control equipment : coordinate supply with load

☆ Electric power grid :

- An integrated web of consumers and generators over a large area.
- India has 5 regional grids (4 dir & 1 north east)
  Southern grid - most consuming
  north east grid - least consuming (produce more than consume)
- These 5 grids are connected to one main grid. (one nation one grid). (since 2013)
  Total transmission capacity - 105,000 MW

  [own & operate] → PGCIL - Power grid corporation of India
  POSOCO - Power system operation corporation of India
- In islands like Andaman or Lakshadweep, the power is not connected to the ~~grd~~ grid since they are archipelagos and are far from main land.
- How can power be transfered from lets say Meghalaya to TN if TN needs to buy power?
  IEX - Indian Energy exchange
  (sort of a trading platform)
  (based on PPP - power purchasing agreements)
- Dynamic pricing:
  If power is taken from the grid in the peak hours, then the cost is more since power demand at that time is max [6-9 morn & eve]
  As a country, we follow "Static pricing".

☆ Power system examples :

- Interconnection: ranges frm quite smol (island) to covering half of the continent. [5 in India, 60 Hz AC]
- Airplanes & spaceships: reduction in weight is primary consideration ; frequency = 400 Hz.
- Ships & submarines
- Automobiles : DC with 12 V standard.

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☆ Power:

- Instantaneous rate of consumption of Energy
- Power = Voltage × current for dc
- Units ⇒ Watts = amp times volts (W)

$$\left[\begin{array}{l} W = A \times V = V \times i \\ kW = 1 \times 10^3 W \\ MW = 1 \times 10^6 W \\ GW = 1 \times 10^9 W \end{array}\right]$$

☆ Energy:

- Integration of power over time
- Work done overtime or ability to do work.
- Units ⇒ $\left[\begin{array}{l} \text{Joule} = 1 \text{ watt-second (J)} \\ kWh = \text{kilowatthr} = 3.6 \times 10^6 J \\ Btu = 1055 J \\ MBtu = 0.292 MW \end{array}\right]$

- All forms of E can be converted to other forms
- E can neither be created nor be destroyed can only be converted from one form to another.

Renewable:
- can be regenerated in a relatively short period of time ; Unlimited

Non-renewable:
- cant be regenerated in a short amt of time ; Limited.

- SERC & CERC - central & state electricity regulatory comission fixes the tariff for each unit of power.

- Non renewable ⇒ Thermall >> Hydro > Nuclear > Bhutan imp

Renewable ⇒ Wind & Solar > Bagasse > Small Hydel > Biomass > (Ethanol from sugar ferment)

Others

- As a country we fulfill the energy requirement with the energy available and thus we are power suffient
(Consumers)
- Domestic ≥ Industrial (high voltage) > Agriculture > commercial > Industrial (med & low voltage)

* BATTERIES

$$\text{BATTERIES} \rightarrow \begin{cases} \text{Electrodes} \\ \text{Electrolytes} \end{cases}$$

- Lithium-ion has very high energy density.
- The change in voltage between a fully charged to a discharged battery is not very high.
- But it is not much safe; very unstable.
- Other than Li-ion batteries, there are
  → Na-ion → Fe-ion → Metal-air.
- Solid state batteries use ceramic as electrodes
  400 Wh / Kg ⇒ energy density.

☆ Battery terminology:

Primary battery – single use
Secondary battery – can be recharged

- are the smallest indv electrochemical unit and deliver a voltage that depends on its chemistry
- Combination of cells – battery
- Batteries and battery packs are made up of group of cells wired in series / parallel.
  - Sometimes packed in a single physical unit
  - For ex; automotive 12V ⇒ 6 2V cells in series
  - sometimes connections are external to the cells.
- "Cell capacity" specifies the quantity of charge in (Ah) or (mAh) that the cells are rated to hold
  3000 mAh ⇒ 3 Ah
- "C rate" is a relative measure of cell's electrical current

[65 mm height
18 mm csection]

[18650 3.7V 3400 mAh]

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- It is the constant charge or discharge rate that the cell can sustain for an hour
- 20 Ah cell should deliver 20A ("1C") for 1 hour or 2A ("C/10") for 10 hours.

- Cell stores energy in electrochemical form.
- Total energy storage capacity is roughly its [nominal voltage × nominal capacity]
  (mWH, Wh, kWh)
- Ex: Nominal energy storage capacity of this is
  $\Rightarrow 3.7 V \times 3.4 Ah = 12.58 Wh$

☆ Cells connected in series:
- Lifetime of a battery can be understood by its "charging cycles" = 1 charge + 1 discharge
- Efficient way to optimise a battery's lifetime is by charging less frequently.
  (ie) less number of charging cycles.
- Also, dont use a device when its being charged since charging & discharge happens simultaneously and thus more and more cycles.
- Using a phone when it has less charge is proning the device to use more energy to sustain proper stability. So, not advisable.

☆ Cells connected in series:
- Battery voltage = sum of voltages of cells
- Battery capacity = individual cell capacity since same i flows thrg all cells.
- Ex: A battery constructed from 3 3V, 20 Ah cells in series will have:
  Nominal voltage = $3 \times 3V = 9V$
  Nominal capacity = $1 \times 20Ah = 20Ah$
  Nominal E capacity = $3 \times 3V \times 20Ah = 180 Wh$

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★ Cells connected in parallel:

- Battery voltage = voltage of indv cells
- Battery capacity = sum of cells' capacities
current is the sum of currents.
- 3V, 20Ah cells in parallel (3 nos)
  - Nominal voltage = 3×3V = 3V
  - Nominal capacity = 3 × 20Ah = 60 Ah
  - Nominal energy cap = 3 × 3V × 20Ah = 180 Wh
- Connecting in parallel usually; the cells must have same capacities (is prefered)

★ Battery charging:

- Cells are often charged (initially) with either constant current or constant power (0-90%)
- When max permitted cell voltage is reached; the cell is charged held at that voltage until fully charged (constant voltage)
This is aka Trickle charging.
- Taking 0-70% is easier and 70% to 100% requires almost double the amount of energy req.

- Specific energy & energy density measure the max stored energy per unit weight or volume resp.
- For a given weight, higher specific energy stores more energy.
For a given volume, higher energy density stores more energy
- For a given storage capacity, higher specific energy cells are lighter
For a given storage capacity, higher energy density cells are smaller.

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☆ Battery characteristics:

- Size
  - Physical – button, AAA, AA, C, D
  - Energy density (watts per kg or cm^3)
- Longevity
  - Capacity (Ah, for drain of C/10 at 20°C)
  - No of recharge cycles
- Discharge characteristics (voltage drops)

☆ Lead Acid Batteries:

Chemistry :
→ Lead
→ Sulphuric acid electrolyte

Features :
+ Least expensive
+ Durable (No memory effect)
– Low energy density
– Toxicity – Self discharge
+ Sufficient resources of Pb
+ Can recover 90% Pb & recycled.

Lithium ion battery:

Chemistry :
→ Graphite (–) ; Co or M (+)
→ Non aqueous electrolyte

Features :
+ 40% more capacity than NiCd
+ Flat discharge (like NiCd)
+ Self discharge 50% less than NiCd
– Expensive

Lithium ion batteries in Gadgets:

- Lithium – greatest electrochemical potential, lightest of all metals. (But Li explosive so use complex)
- Overcharging might pose problem or explosion so Battery management system exists.

* ELECTROSTATICS:

* Battery management systems (BMS)
  - Comprises of purpose built electronics and custom designed algorithms. (Software + Hardware)
  - Pb acid battery doesn't require BMS but Li ion needs it due to 'C' rate
  - If PbA battery is not maintained at a high state of charge, $PbSO_4$ deposits on both electrodes and form hard crystals which cant be reconverted by a standard fixed V charger (13.6V)
  - In Li ion batteries even 0.1V variation for a small period of time causes release of flamable gases & battery bulging & explosion

Atoms → P^+, N, E^- — positron, quarks, neutrinos, antineutrinos, Higgs Boson, etc (17 subatomic)

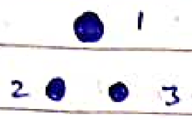
* Definition:
  - The branch of engineering which deals with the flow of electrons is called current electricity
  - Charges (e) do not move but remain static on the bodies. This branch that deals with charges at rest is called 'Electrostatics'.

* Electric charge:
  - To quantify electric charge, we label the amt of charge on a body as q (−q or +q)
  - charge is quantised

    q = multiple of an elementary charge 'e'

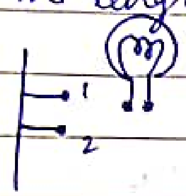
    $q = \pm ne$ $\qquad e = 1.6 \times 10^{-19}$ C
  - p & n are made of Quarks, whose charge is quantised in multiples of e/3. Quarks cant be isolated.

- Lightning - charge transfer. - 40000 A - 40K C/s
"Intermittent" - these renewable sources (lightning) huge amount of voltage & current and it is not stable over a long period of time.
- Protect a building from lighting by earthing / grounding. The 3rd middle pin is the earthing pin. The electrons are transferred to the ground (sea of e-)



1 - earth
2 - phase
3 - neutral

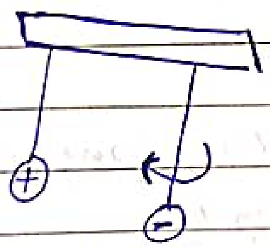
The cross section is more - resistance less, so the current gets earthed more easily and quickly
The length of pin 1 is longer to prevent shocks



case 1 - Glows P P / N E (higher and lower potentials)
- No glow

Some applications:
- Electrostatic generators for X-ray
- Spray of paints, powder
- Fly ash capture
- capacitors
- Development of lighting rod
- Insulation design to avoid sparks in HV circuit (high voltage)

☆ Coulomb's experiment



- degree of twist determines the force

☆ Coulomb's law:

1 → Like charges repel; Unlike attract.
- Unit charge - 1 C
(But we can do magnetic monopoles in magnet).

2 → F between 2 charges $\propto \frac{q_1 q_2}{r^2}$

- Charges approximate to point charges if they are small compared to the dist between them

$$\boxed{\vec{F}_{12} = K\frac{q_1 q_2}{d^2} \times \hat{d}}$$

$$\left[\varepsilon_0 = 8.854\times10^{-12}\right] \text{ (permittivity of free space)}$$

$$\left[K = \frac{1}{4\pi\varepsilon_0} = 9\times10^{9}\ Nm^2/C^2\right]$$

- One coulomb is that charge which when placed in air at a distance of 1m from an equal and similar charge repels it with an $F = 9\times10^9\ N$
- Practical units of charge ⇒ pC (picocoulomb), μC, etc

$$\boxed{\varepsilon = \varepsilon_0 \varepsilon_r}$$

<u>QUE</u>: $Q_1 - 20\,\mu C \quad (0,1,2)$

$Q_2 - -300\,\mu C \quad (2,0,0)$

$F = ?$

$$\hat{R}_{21} = \frac{\vec{R}_{21}}{|\vec{R}_{21}|} = \frac{-2a_x + a_y + 2a_z}{\sqrt{4+4+1}}$$

$$\hat{R}_{21} = \frac{+1}{3}(-2a_x + a_y + 2a_z)$$

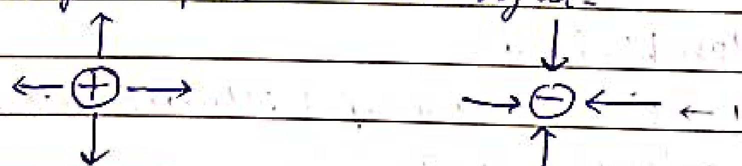
$$\vec{F}_{21} = \left[\frac{-20\times 300\times10^{-12}}{(3)^2}\times 9\times10^{9}\right]\times\left[\frac{-2a_x + a_y + 2a_z}{3}\right]$$

$$= 6\left[\frac{2a_x - a_y - 2a_z}{3}\right] N$$

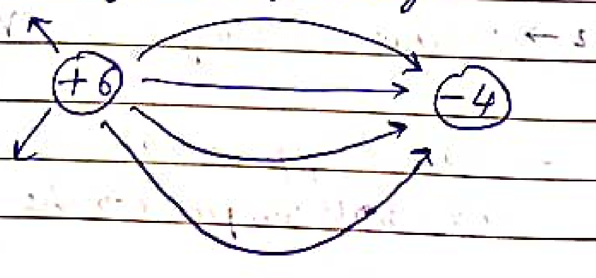
<u>Ans</u>: ⇒ 6 N (attractive)

☆ Electric Field:

- We can say that a charged body changes the nature of the space surrounding it.



- No of arrow $\propto$ magnitude of charge



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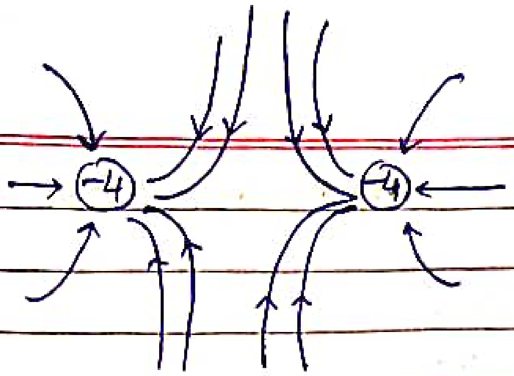


NOTE :
field lines never cross eachother in ANY case

Electric field intensity :
It is the force per unit charge

$$\boxed{E_1 = \frac{F_{12}}{Q_2}}$$

$$\boxed{E = \frac{Q}{4\pi\varepsilon_0 R^2}\, a_R}$$

☆ Smart Grid:

- Interconnection of power generation and the power consumers (digitisation)

⇒ Grid + communication + automation ⟶ Smart grid (Improved performance)

- ATC – Aggregated Technical & commercial losses (26%)

Losses include in the form of heat (resistance), (technical loss)

ATC →
- Technical loss
- Inefficient billing, collection
- Theft (unmetered grids) (8%) Transformer (meter) $\xrightarrow{\text{(non meter)}}$ Home (meter)
- Commercial loss

- How to reduce power theft?

Smart meters; communication & automation in grid

QUE: E at (0, 3, 4) m due to a pt charge Q = 0.5 μC at the origin = ?

$R = 3a_y + 4a_z$

$a_R = (3a_y + 4a_z)/5$

$= (0.6 a_y + 0.8 a_z)$

$E = \frac{0.5 \times 10^{-6}}{4\pi\epsilon_0 \times 5^2} \times a_R$

$= \frac{1}{2} \times \frac{10^{-6} \times 9 \times 10^9}{25} \times a_R$

$E \Rightarrow 180\ V/m \times (0.6 a_y + 0.8 a_z)$ //

QUE: $Q_1 = 25\,nC$ at $P_1(4, -2, 7)$

$\epsilon = \epsilon_0$ Find E at $P_2(1, 2, 3)$

$R = 3a_x + (-4)a_y + 4a_z$

$a_R = (3a_x - 4a_y + 4a_z)/\sqrt{41}$

$E = \frac{25 \times 10^{-9} \times 9 \times 10^9}{41} \times \left(\frac{3a_x - 4a_y + 4a_z}{\sqrt{41}}\right)$

$\Rightarrow \frac{25 \times 10^{-9}}{4\pi\epsilon_0 (41)^{3/2}} (-3a_x + 4a_y - 4a_z)$ //

$(|R| = \sqrt{41})$

16
16
9
―
25
16
―
41

☆ CAPACITORS:

- device for storing charge (stores E in electrostatic form)
- simplest example: 2 $\parallel^{el}$ conducting plates seperated by air

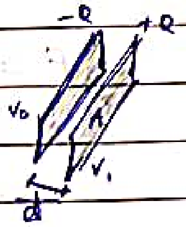
$$\boxed{C = \frac{Q}{V}}$$

- Electric field between the 2 charged plates:

$$\boxed{E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A}}$$

$$\boxed{\Delta V = V_1 - V_0 = -\int_0^d E \cdot d\vec{l} = Ed}$$

$$\boxed{C = \frac{Q}{\Delta V} = \frac{Q}{Ed} = \frac{\varepsilon_0 A}{d}}$$



QUE: $d = 0.001 m$ $A = 0.2m \times 0.03m$

$$C = \frac{\varepsilon_0 A}{d} = \frac{8.85 \times 6 \times 10^{-3} \times 10^{-12}}{1 \times 10^{-3}}$$

$$= 53.1 \times 10^{-12}$$

$$\Rightarrow 5.31 \times 10^{-11}$$

$\Delta V = 12V$

$$Q = CV = 5.31 \times 12 \times 10^{-11}$$

$$= 63.72 \times 10^{-11}$$

$$\Rightarrow 6.372 \times 10^{-10}\ C$$

$$E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A} = \frac{6.372 \times 10^{-10}}{8.85 \times 10^{-12} \times 6 \times 10^{-3}}$$

$$= \frac{0.72 \times 10^5}{6}$$

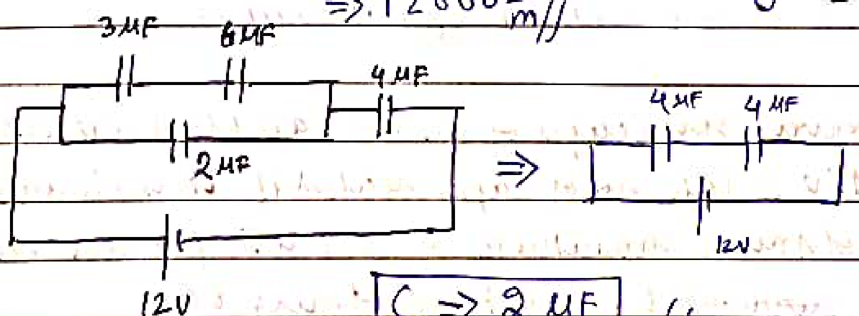
$$= 0.12 \times 10^5$$

$$\Rightarrow 12000 \frac{V}{m}$$

or

$$E = \frac{\Delta V}{d} = \frac{12}{0.001} = 12000$$

QUE:



$$\boxed{C_{eq} \Rightarrow 2\,\mu F}$$

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★ Capacitance of concentric spheres:

(Electric field) $\boxed{E = \frac{Q}{4\pi\varepsilon_0 r^2}}$ $\boxed{\Delta V = \frac{Q}{4\pi\varepsilon_0}\left[\frac{1}{a} - \frac{1}{b}\right]}$

$$\boxed{C = \frac{Q}{\Delta V} = \frac{4\pi\varepsilon_0}{\left[\frac{1}{a} - \frac{1}{b}\right]}}$$

$$\boxed{E = \frac{1}{2}CV^2}$$

∴ Stored energy is the reason why a capacitor can produce an electric shock even when its not connected to a circuit.

QUE: $\parallel^{el}$ plate cap; $A = 0.25\,m^2$ $d = 6 \times 10^{-3}\,m$ $V = 12$

- $C = \frac{\varepsilon_0 A}{d} = \frac{8.85 \times 25 \times 10^{-14}}{6 \times 10^{-3}}$

$= 36.875 \times 10^{-14}$

$\Rightarrow 3.68 \times 10^{-8}\,F$ //

- $Q = CV = 3.68 \times 12 \times 10^{-13}$

$= 44.16 \times 10^{-13}$

$\Rightarrow 4.416 \times 10$

- $U = \frac{1}{2}CV^2 = \frac{1}{2} \times 3.6 \times 10^{-8} \times (12)^2$

$\boxed{U = 2.66 \times 10^{-6}\,J}$ //

~~(C) when V across capacitor is halved, Q is halved and U doubles~~ $Q = CV$ $U = \frac{1}{2}CV^2$

QUE. Given some caps of $0.1\,\mu F$ capable of withstanding 15V. Calc no of caps needed if it is desired to obtain capacitance of $0.1\,\mu F$ for use in a ~~current~~ circuit involving 60V.