
**EEE108 Electromagnetism and Electromechanics**

# Lecture 23

# Module Revision

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Recall

## Module Syllabus

### Electromagnetism

- Introduction to simple electrostatics
- Electrical Current
- Maxwell's Equation:
  - Gauss's Law
  - Ampere's Law
  - Gauss's law for magnetism
  - Faraday's Law

### Drives

- Electromagnetic induction
- Moving coil transducers
- Linear actuators
- Transformer
- DC rotating machines
- AC rotating machines



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## Revision

Mini-review of Electrostatics

Class Revision:

Yourself revision: most important

not necessary to do math too much!

### Important

- Make sure you do the homework independently
- Re-work the examples in the lecture notes



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## Vectors, Coordinate Systems and Divergence Theorem

**Vectors:**

1. What are vectors?
2. Vector Notation
3. Vector Representation
4. Vector Operations:
   - Addition and subtraction
   - Dot product
   - Cross product
5. Integral: Line Integral
   Surface Integral

**Divergence Theorem -- Three Operators:**

1.Gradient $\nabla T = \mathbf{a}_x \frac{\partial T}{\partial x} + \mathbf{a}_y \frac{\partial T}{\partial y} + \mathbf{a}_z \frac{\partial T}{\partial z}$

2.Divergence $\nabla \bullet \mathbf{A} = \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z}$

3.Laplacian $\Delta T = \nabla^2 T = \nabla \bullet \nabla T$

$$\Delta T = \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}$$

**Three orthogonal coordinate systems:**

1.Cartesian/Rectangular $(x, y, z)$
2.Cylindrical $(r, \varphi, z)$
3.Spherical $(R, \theta, \varphi)$

Expression : $d\mathbf{l}, d\mathbf{A}, dV$

Cartesian :

$d\mathbf{l} = dx\, \mathbf{a}_x + dy\, \mathbf{a}_y + dz\, \mathbf{a}_z$

$dl = \sqrt{(dx)^2 + (dy)^2 + (dz)^2}$

## Summary of Vector Relations

| | Cartesian Coordinates | Cylindrical Coordinates | Spherical Coordinates |
|---|---|---|---|
| **Coordinate variables** | $x,y,z$ | $r,\phi,z$ | $R,\theta,\phi$ |
| **Vector representation, A** | $\mathbf{a}_x A_x + A_y\,\mathbf{a}_y + A_z\,\mathbf{a}_z$ | $\mathbf{a}_r A_r + A_\phi\,\mathbf{a}_\phi + A_z\,\mathbf{a}_z$ | $\mathbf{a}_R A_R + A_\theta\,\mathbf{a}_\theta + A_\phi\,\mathbf{a}_\phi$ |
| **Magnitude of A, $\lvert A\rvert$** | $\sqrt[+]{A_x^2+A_y^2+A_z^2}$ | $\sqrt[+]{A_r^2+A_\phi^2+A_z^2}$ | $\sqrt[+]{A_R^2+A_\theta^2+A_\phi^2}$ |
| **Base vectors properties** | $\mathbf{a}_x\bullet\mathbf{a}_x=\mathbf{a}_y\bullet\mathbf{a}_y=\mathbf{a}_z\bullet\mathbf{a}_z=1$<br>$\mathbf{a}_x\bullet\mathbf{a}_y=\mathbf{a}_y\bullet\mathbf{a}_z=\mathbf{a}_z\bullet\mathbf{a}_x=0$<br>$\mathbf{a}_x\times\mathbf{a}_y=\mathbf{a}_z,\quad \mathbf{a}_y\times\mathbf{a}_z=\mathbf{a}_x$<br>$\mathbf{a}_z\times\mathbf{a}_x=\mathbf{a}_y$ | $\mathbf{a}_r\bullet\mathbf{a}_r=\mathbf{a}_\phi\bullet\mathbf{a}_\phi=\mathbf{a}_z\bullet\mathbf{a}_z=1$<br>$\mathbf{a}_r\bullet\mathbf{a}_\phi=\mathbf{a}_\phi\bullet\mathbf{a}_z=\mathbf{a}_z\bullet\mathbf{a}_r=0$<br>$\mathbf{a}_r\times\mathbf{a}_\phi=\mathbf{a}_z,\quad \mathbf{a}_\phi\times\mathbf{a}_z=\mathbf{a}_r$<br>$\mathbf{a}_z\times\mathbf{a}_r=\mathbf{a}_\phi$ | $\mathbf{a}_R\bullet\mathbf{a}_R=\mathbf{a}_\theta\bullet\mathbf{a}_\theta=\mathbf{a}_\phi\bullet\mathbf{a}_\phi=1$<br>$\mathbf{a}_R\bullet\mathbf{a}_\theta=\mathbf{a}_\theta\bullet\mathbf{a}_\phi=\mathbf{a}_\phi\bullet\mathbf{a}_R=0$<br>$\mathbf{a}_R\times\mathbf{a}_\theta=\mathbf{a}_\phi,\quad \mathbf{a}_\theta\times\mathbf{a}_\phi=\mathbf{a}_R$<br>$\mathbf{a}_\phi\times\mathbf{a}_R=\mathbf{a}_\theta$ |
| **Dot product, A·B** | $A_xB_x+A_yB_y+A_zB_z$ | $A_rB_r+A_\phi B_\phi+A_zB_z$ | $A_RB_R+A_\theta B_\theta+A_\phi B_\phi$ |
| **Cross product, A × B** | $\begin{vmatrix}\mathbf{a}_x & \mathbf{a}_y & \mathbf{a}_z\\ A_x & A_y & A_z\\ B_x & B_y & B_z\end{vmatrix}$ | $\begin{vmatrix}\mathbf{a}_x & \mathbf{a}_\phi & \mathbf{a}_z\\ A_r & A_\phi & A_z\\ B_r & B_\phi & B_z\end{vmatrix}$ | $\begin{vmatrix}\mathbf{a}_R & \mathbf{a}_\theta & \mathbf{a}_\phi\\ A_R & A_\theta & A_\phi\\ B_R & B_\theta & B_\phi\end{vmatrix}$ |



## Electromagnetism

- – Introduction to Simple Electrostatics
- – Gauss's Law
- – Gauss's Law for Magnetism
- – Ampere's Law
- – Faraday's Law
- – Magnetic Circuits

- Be able to state the laws in words and in equations in the integral form
- Understand the meaning of each item in the equations
- And know how to use them to solve the problems directly in the special conditions.



## Electrostatics

➢Coulomb's Law: electrical force: two point charges: $\mathbf{F}_{12} = k_e \dfrac{Q_1Q_2}{r^2}\mathbf{a}_r$

➢Electric field and electric potential: electric field for a point charge:

$$\mathbf{E} = k_e \frac{q}{r^2}\mathbf{a}_r$$

➢Electric flux and electric lines

➢Gauss's law: $\Phi_E = \oiint_S \mathbf{E}\bullet d\mathbf{s} = \dfrac{Q_{enc}}{\varepsilon_0}$ or $\oiint_S \mathbf{D}\bullet d\mathbf{s} = Q_{enc}$

Calculating the electric field for a system that possesses planar, cylindrical or spherical symmetry.

➢Electric potential $\varphi_{21} = \varphi_2 - \varphi_1 = -\int_{P_1}^{P_2}\mathbf{E}\bullet d\mathbf{L}$ $\qquad \varphi = -\int_{\infty}^{P}\mathbf{E}\bullet d\mathbf{L}$ (V)

➢Electric energy/electric potential energy $\Delta U = q_0\,\Delta\varphi$



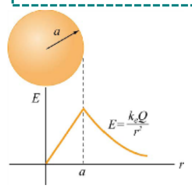
## Gauss's law

$$\Phi_E = \oiint_S \mathbf{E}\bullet d\mathbf{s} = \frac{Q_{enc}}{\varepsilon} \qquad \oiint_S \mathbf{D}\bullet d\mathbf{s} = Q_{enc}$$

Spherical Symmetry

$$\mathbf{E} = \frac{Q}{4\pi\varepsilon_0}\frac{r}{a^3}\mathbf{a}_r \quad r<a$$

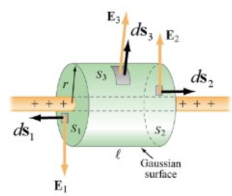
$$\mathbf{E} = \frac{Q}{4\pi\varepsilon_0 r^2}\mathbf{a}_r \quad r>a$$




**Non-conducting solid sphere**

Cylindrical Symmetry

$$\mathbf{E} = \frac{\rho_L}{2\pi\varepsilon_0 r}\mathbf{a}_r$$

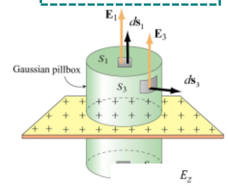



**Infinitely long rod**

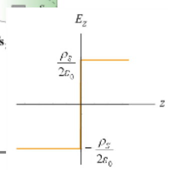
Planar Symmetry

$$\mathbf{E} = \frac{\rho_S}{2\varepsilon_0}\mathbf{a}_z \quad z\ge 0$$

$$\mathbf{E} = -\frac{\rho_S}{2\varepsilon_0}\mathbf{a}_z \quad z\le 0$$

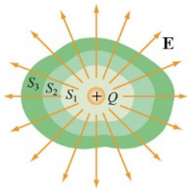



**Infinite slab**



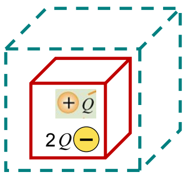
## Examples

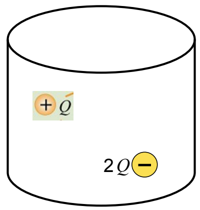
The total “flux” of field lines penetrating any of these surfaces is the same and depends only on the amount of charge inside.




In free space:

$$\Phi_E = \oint\!\!\oint_S \mathbf{E} \bullet d\mathbf{s} = \frac{Q_{enc}}{\varepsilon_0}$$






## Electrostatics

➢**Electric dipole: dipole moment vector:** $\mathbf{p} = Qd\mathbf{a}_p$

➢**Insulators and conductors: the basic properties of conductors in electrostatic equilibrium**

➢**Capacitance: definition: $C = Q/V$, connections: Series, Parallel**

**energy density stored in:** $u_E = \frac{U_E}{\text{Volume}} = \frac{1}{2}\varepsilon E^2$ , **energy stored:** $\frac{1}{2}CV^2$

**with dielectrics:** $C = \varepsilon_r C_0$

**three typical capacitors: Prototypical, Cylindrical and Spherical**

What should you remember?
•Parallel plate capacitor: very well
•Be able to derive the other standard geometries: cylindrical and spherical

More information: **Mini-review of Electrostatics**



## Magnetism

- ❖ Gauss's Law for Magnetism
- ❖ Ampere’s Law
- ❖ Faraday’s Law
- ❖ Magnetic Circuits

•Be able to state the laws in words and in equations in the integral form

•Understand the meaning of each item in the equations

•And know how to use them to solve the problems directly in the special conditions.



## Magnetism

➢Magnetic field: **B** and **H,** the relationship between them

➢Magnetic flux and magnetic flux lines

➢Moving charges/current create magnetic field : **B** – magnitude and direction

➢Magnetic field exerts a force on any other moving charges/current:

**F** – magnitude and direction

➢Lorentz Force: $\mathbf{F}_{\text{Lorentz}} = \mathbf{F}_E + \mathbf{F}_B = q\mathbf{E} + q(\mathbf{v} \times \mathbf{B})$

➢Torque on a current loop

➢Gauss’s Law for Magnetism: $\oint\!\!\oint_S \mathbf{B} \bullet d\mathbf{A} = 0$

➢Ampere’s Law: $\oint \mathbf{B} \bullet d\mathbf{L} = \mu_0 I_{enc}$

An infinite wire, an ideal solenoid, a toroid and infinite current sheet.

➢Faraday’s law: $\varepsilon = -\frac{d\Phi_B}{dt}$

➢Lenz’s Law: The induced emf must be in the direction that opposes the change.

## Magnetism

- Mutual Inductance: $\varepsilon_{21} = -N_2 \dfrac{d\Phi_{21}}{dt} = \boxed{M} \dfrac{dI_1}{dt}$
- Self-Inductance: $\varepsilon_L = -N \dfrac{d\Phi_B}{dt} = -\boxed{L} \dfrac{di}{dt}$
- Inductor: energy stored $\frac{1}{2} L I^2$
- RL circuit: time constant $\tau = L/R$
- Magnetic Materials: Ferromagnetic, Paramagnetic, and Diamagnetic

Then the density of energy : $w_m = \int_0^B H dB \quad \text{J/m}^3$

- Magnetic circuits : $F = \Re_{eq} \Phi$

$$\Re_{eq} = \Re_1 + \Re_2 + \ldots + \Re_n = \sum_{i=1}^{n} \Re_i \quad \text{in series}$$

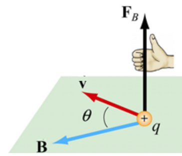
$$\frac{1}{\Re_{eq}} = \frac{1}{\Re_1} + \frac{1}{\Re_2} + \ldots + \frac{1}{\Re_n} = \sum_{i=1}^{n} \frac{1}{\Re_i} \quad \text{in parallel}$$



## Magnetic Force

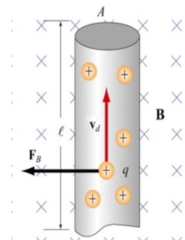
$$\mathbf{F}_B = q\mathbf{v} \times \mathbf{B} = |q| vB \sin\theta$$

Force on moving charge partical




$$\mathbf{F}_B = I(\mathbf{l} \times \mathbf{B})$$

Force on Current-Carrying Wire




SI unit of $\mathbf{B} = \dfrac{\text{N}}{\text{C} \cdot \text{m/s}} = \dfrac{\text{N}}{\text{A} \cdot \text{m}}$



## Magnetic Dipole Moment

***magnetic dipole moment*** :

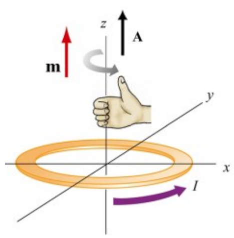
$\mathbf{m} = I\mathbf{A}$

In terms of $\mathbf{m}$, the torque vector $\mathbf{T}$ can be written as :

$\mathbf{T} = \mathbf{m} \times \mathbf{B}$

***magnetic dipole moment*** *of a loop with N turns* :

$\mathbf{m} = NI\mathbf{A}$



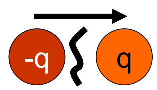

Right-hand rule:
When the thumb of the right hand is pointed along the direct of the torque, the four fingers indicate the direction that the torque is trying to rotate the body.



## Gauss's Law for Magnetism

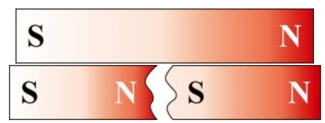
### Magnetic Monopoles

Electric Dipole




When cut:
2 monopoles (charges)

Magnetic Dipole




When cut: 2 dipoles

Magnetic monopoles do not exist in isolation

$$\oiint_S \mathbf{E} \bullet d\mathbf{s} = \frac{q_{enc}}{\varepsilon_0}$$

Gauss's Law

$$\oiint_S \mathbf{B} \bullet d\mathbf{s} = 0$$

Gauss's Law for Magnetism

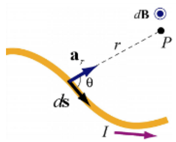
## Biot-Savart Law

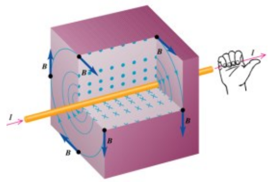
Current $I$ flowing through a different length $d\mathbf{L}$
(or equivalently charge $q$ with velocity $\mathbf{v}$)
produces a magnetic field :

$$d\mathbf{B} = \frac{\mu_0}{4\pi}\frac{Id\mathbf{L}\times\mathbf{a}_r}{r^2}$$

$$\mathbf{B} = \frac{\mu_0}{4\pi}\frac{q\mathbf{v}\times\mathbf{a}_r}{r^2}$$

Right-hand rule:
Thumb: points direction of the current.
Four fingers curl in the direction of the magnetic field lines.



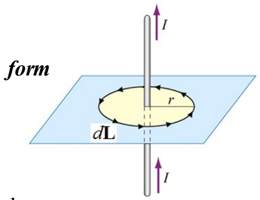





## Ampere's Law

The line integral of $\oint \mathbf{B}\bullet d\mathbf{L}$ around any closed Amperian loop is proportional to $I_{enc}$ , the current encircled by the loop.

$$\oint \mathbf{B}\bullet d\mathbf{L} = \mu_0 I_{enc} \quad \Leftarrow \quad \textit{Ampere's law integral form}$$




***Differential form***

By the Kelvin - Stokes theorem, this equation can also be written in a differential form :

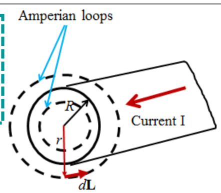
$$\nabla\times\mathbf{B} = \mu_0\mathbf{J} \quad \Leftarrow \quad \textit{Ampere's law differential form}$$

where $\mathbf{J}$ is the current density through the surface enclosed by the Amperian loop.



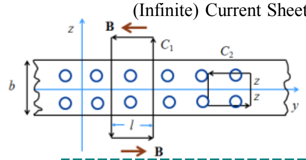
## Ampere's Law: $\oint \mathbf{B}\bullet d\mathbf{L} = \mu_0 I_{enc}$

$$\boxed{\begin{aligned} B &= \frac{\mu_0 I r}{2\pi R^2} \quad r<R \\ B &= \frac{\mu_0 I}{2\pi r} \quad r\ge R \end{aligned}}$$



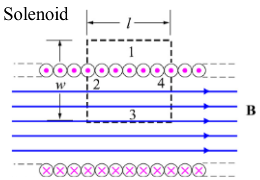

Long Circular Symmetry

(Infinite) Current Sheet



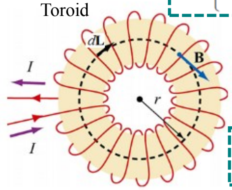

$$\boxed{\mathbf{B} = \begin{cases} -\dfrac{\mu_0 J_0 b}{2}\mathbf{a}_y, & z>b/2 \\ -\mu_0 J_0 z\,\mathbf{a}_y, & -b/2<z<b/2 \\ \dfrac{\mu_0 J_0 b}{2}\mathbf{a}_y, & z<-b/2 \end{cases}}$$

Solenoid




$$\boxed{B = \frac{\mu_0 N I}{l} = \mu_0 n I}$$

Toroid




$$\boxed{B = \frac{\mu_0 N I}{2\pi r}}$$



## Faraday's Law of Inductance

The induced emf $\varepsilon$ in a coil with $N$ turns is proportional to the negative of the rate of change of magnetic flux.

$$\varepsilon = -N\frac{d\Phi_B}{dt}$$

$$\varepsilon = \oint_l \mathbf{E}\bullet d\mathbf{L} = -\frac{d\Phi_B}{dt} \quad \text{Integral form}$$

Minus sign?
Lenz's law:
The induced current produces magnetic fields which tend to oppose the change in magnetic flux that induces such currents.

•A changing magnetic flux induces an EMF.

•Ways to induce EMF:

Change:

*Magnitude of $B$

*Area $A$ enclosed by the loop

*Angle $\theta$ between $B$ and loop normal

## Mutual Inductance and Self Inductance

By varying $I_1$ with time, there will be an induced

emf in coil 2 : $\varepsilon_{21} = -N_2 \dfrac{d\Phi_{21}}{dt}$

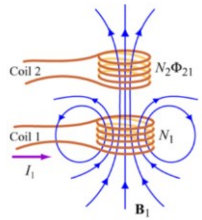
The rate of change of $\Phi_{21}$ in coil 2 is proportional to the time rate of change of the current in coil 1 :

$$N_2 \frac{d\Phi_{21}}{dt} = M_{21} \frac{dI_1}{dt}$$

M: mutual inductance

$$M_{21} = \frac{N_2\Phi_{21}}{I_2} \qquad M_{12} = M_{21} = M$$

$$\Rightarrow \quad \varepsilon_{21} = -M \frac{dI_2}{dt}$$



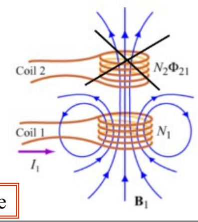

The self - induced emf :

$$\varepsilon_L = -N \frac{d\Phi_B}{dt} = -L \frac{dI}{dt}$$

where the self - inductance :

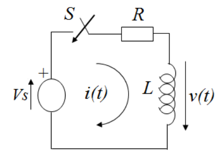
$$L = \frac{N\Phi_B}{I}$$

L: self inductance

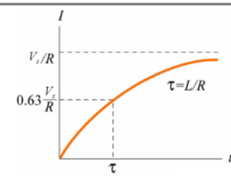





## RL Circuits




Kirchhoff's loop rule




$$i(t) = \frac{V_s}{R}(1 - e^{-t/\tau})$$

$\tau = L/R$: time constant of the system

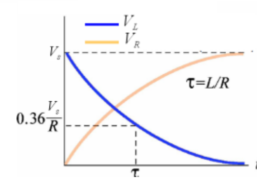
$$\sum V_i = V_s - iR - L\frac{di}{dt} = 0$$

$$\Rightarrow \quad \frac{L}{R}\frac{di}{dt} = -(I - \frac{V_s}{R})$$

The magnetic energy stored in a inductor

$$U_B = \frac{1}{2}LI^2$$

Stored in magnetic field.




$t = 0^+$: Current is changing. Inductor works: to stop the changing

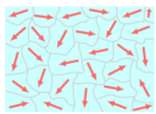
$t = \infty$: Current is steady. Inductor does nothing.



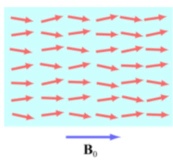
## Magnetic Materials

$\mathbf{B} = \mu_0\mathbf{H}$ free space

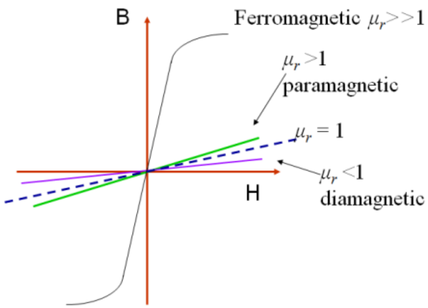
$\mathbf{B} = \mu\mathbf{H} = \mu_0\mu_r\mathbf{H}$



Unmagnetized domains




Magnetized domains

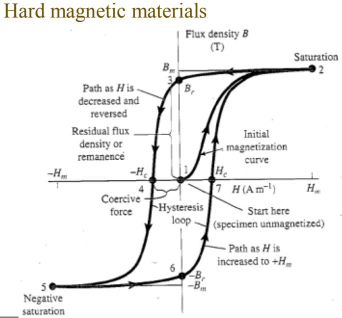





## Ferromagnetic Material

### Magnetic Hysteresis

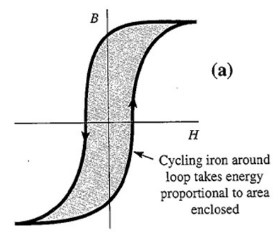
- Hysteresis loop
- Residual flux density
- Coercive force
- Saturation
- Soft magnetic materials
- Hard magnetic materials




### Energy in a Magnets

Then the density of energy is :

$$w_m = \int_0^B H dB \quad \text{J/m}^3$$




The area between the cure and the $B$ axis is a measure of the energy density.

## Transformer

- A transformer converts AC power at one voltage level to AC power of the same frequency at another voltage level.
- Operation Principles: Faraday's induction law
- Ideal transformers: a lossless device with an input winding and an output winding:
  - the windings have no resistance,
  - loss-less magnetic core,
  - reluctance of the core is zero.

$$\boxed{\frac{V_p}{V_s}=n \quad \frac{I_p}{I_s}=\frac{1}{n} \quad \frac{Z_p}{Z_s}=n^2 \quad P_{in}=P_{out}}$$

- Real Transformers
  - Copper ($I^2R$) Losses
  - Eddy Current Losses
  - Hysteresis Losses
  - Leakage Flux
- Two important performance characteristics:

Voltage regulation:

$$VR=\frac{V_{2,nl}-V_{2,fl}}{V_{2,fl}}\times 100\%$$

Efficiency

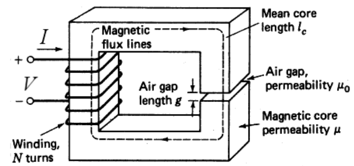
$$\eta=\frac{P_{out}}{P_{in}}\times 100\%=\frac{P_{out}}{P_{out}+P_{loss}}\times 100\%$$

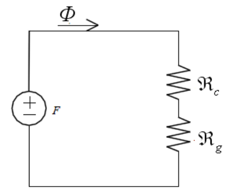
- The maximum efficiency: when the copper loss is equal to the core loss:

$$I_2^2R_{eq}=P_{core}$$



## Magnetic Circuits



Series magnetic circuit

By Ampere's law

$$F=NI=H_cl_c+H_gl_g$$

$$\text{where } H_cl_c=\frac{B_c}{\mu_c}l_c=\frac{\Phi_c}{\mu_cA_c}l_c=\Phi_c\Re_c$$

$$\text{and } \quad H_gl_g=\frac{B_g}{\mu_0}l_g=\frac{\Phi_g}{\mu_0A_g}l_g=\Phi_g\Re_g$$

According to Gauss's law in magnetics :

$$\oint_S \mathbf{B}\bullet d\mathbf{A}=0$$

We have : $\Phi_c=\Phi_g=\Phi$

Therefore $\boxed{F=(\Re_c+\Re_g)\Phi}$

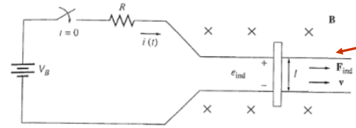


## Electrical Machines

- AC Machines
  - Synchronous
    - Generators (popular)
    - Motors
  - Induction
    - Motors (Three-phase)
- DC Machines
  - Generators
  - Motors



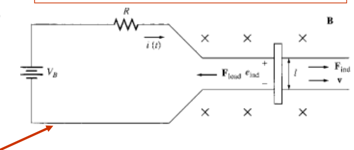
## Linear DC Machine



Starting a linear DC machine

$F=0$, $e_{ind}=V_B$, $i=0$, and $v_{ss}=V_B/Bl$.

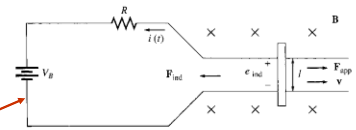
$I_{start}=V_B/R\ \uparrow$



The linear DC machine as a motor

$F_{ind}=F_{load}$ (with opposite directions) at a lower speed $v$.

Electric power $e_{ind}i$ is being converted to mechanical power $F_{ind}v$



The linear DC machine as a generator

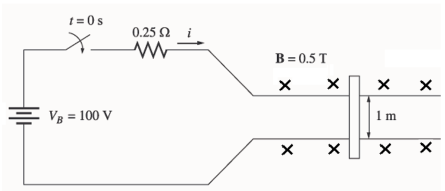
$F_{ind}=F_{app}$ (with opposite directions) at a higher speed $v$.

Mechanical power $F_{ind}v$ is being converted to electric power $e_{ind}i$

## Recall Linear DC Machine

### Example

A linear machine has a magnetic flux density of 0.5 T directed into the page, a resistance of 0.25 Ω, a bar length $l = 1.0$ m, and a battery voltage of 100 V.
(a) What is the initial force on the bar at starting? What is the initial current flow?
(b) What is the no-load steady-state speed of the bar?
(c) If the bar runs off into a region where the flux density falls to 0.40 T, what is the no-load steady-state speed of the bar?
(d) If the bar is loaded with a force of 25 N opposite to the direction of motion, what is the new steady state speed? What is the efficiency of the machine under these circumstances?






## DC Machines

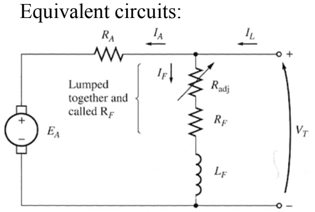
- Operating principle
- Construction:
  two windings: field windings on stator
  armature windings on rotor
- Types:
  separately excited, shunt, permanent-magnet, series, and compounded.
- Equivalent circuits, terminal characteristics, speed/voltage control
- Efficiency and losses



## DC Machines

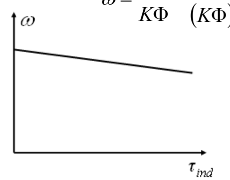
**DC shunt motors**

Equivalent circuits:




Terminal characteristics:

$$\omega = \frac{V_T}{K\Phi} - \frac{R_A}{(K\Phi)^2}\tau_{ind}$$




Speed control:

Two common methods:

- Adjusting the field resistance $R_F$
- Adjusting the terminal voltage applied to the armature.

The cause-and-effect behavior involved in the field resistance increases:



## Electrical Frequency and Speed of Rotor

$$f_e = \frac{n_m P}{120} \quad \text{or} \quad n_m = \frac{120 f_e}{P}$$

where is $f_e$ electric frequency, in Hz
$n_m$ : mechanical speed of magnetic field (= rotor speed), in r/min
$P$ : number of poles

$$f_m = \frac{n_m}{60} \Rightarrow f_e = \frac{P}{2} f_m$$

$$\theta_e = \frac{P}{2}\theta_m \qquad \omega_e = \frac{P}{2}\omega_m$$

| | Rotor speed $n_m$ (r/min) | |
|---|---|---|
| No. of poles ($P$) | 60 Hz | 50 Hz |
| 2 | 3600 | 3000 |
| 4 | 1800 | 1500 |
| 6 | 1200 | 1000 |
| 8 | 900 | 750 |
| 10 | 720 | 600 |
| 12 | 600 | 500 |
| 16 | 450 | 375 |
| 18 | 400 | 333 |
| 20 | 360 | 300 |
| 24 | 300 | 250 |
| 32 | 225 | 188 |
| 40 | 180 | 150 |

# AC Machines

•Operating principle

•Construction: two windings: field windings on rotor: advantages

armature windings on stator

| Synchronous generators | Induction motors |
|---|---|
| Magnetic field current is supplied by a separate DC power source | Field current is supplied by magnetic induction into their field windings. |

$$f_e = \frac{n_m P}{120}$$

stator magnetic field $n_{sync} = \dfrac{120 f_e}{P}$

slip speed $n_{slip} = n_{sync} - n_m$

slip $s = \dfrac{n_{slip}}{n_{sync}} \times 100\% = \dfrac{n_{sync} - n_m}{n_{sync}} \times 100\%$

the slip/rotor frequency, electrical frequency on rotor $f_{re} = \dfrac{(n_{sync} - n_m)P}{120}$

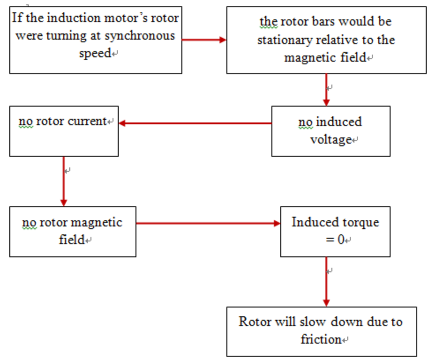
or $f_{re} = s f_{se}$



# AC Machines

•Induction motors: speed limitation:

an induction motor can speed up to near synchronous speed but it can never reach synchronous speed in its normal operation






# AC Machines

Synchronous generators Induction motors

- Equivalent circuits, terminal characteristics, speed/voltage control
- Efficiency and losses

Example

The rotor of a six-pole synchronous generator is rotating at a mechanical speed of 1200 r/min.

What is the frequency of the generated voltage in hertz?

Example

A 50 kW, 460 V, 50 Hz, two-pole induction motor has a slip of 5% at full-load conditions.

What are the shaft speed, the load torque and the rotor frequency at full-load?



# Final Exam

**2017/18 SEMESTER 2 – FINAL EXAM**

**BACHELOR DEGREE – Year 2**

**Electromagnetism and Electromechanics**

**TIME ALLOWED: 3 Hours**

**INSTRUCTIONS TO CANDIDATES**

Multiple-choice questions: 40 marks

1. This is a CLOSED BOOK exam. Total marks available are 100.
2. Answer ALL questions in Section A and Section B.
3. Multiple choice question answers for Section A should be written in pencil on the MCQ answer sheet.
4. Section B Answers must be written in the answer booklet(s) provided.
5. The number in the column on the right indicates the approximate marks for each question.
6. In answering the questions in Section B, it is particularly important to give reasons for your answer. Only partial marks will be awarded for correct answers with inadequate reasons.
7. The university approved calculator - Casio FS82ES/83ES can be used.
8. A list of useful equations and constant values is provided at the end of this examination paper.

## Final Exam – Time and Location

2017/18 Semester 2 Final Examination Timetable

| Module | Module Leader | Date | Day | Start Time | Duration | Exam Room | No. of Students in Room | Senior Invigilator(s) |
|---|---|---|---|---|---|---|---|---|
| EEE108 | Jinling Zhang | 12-Jun | Tue | 2:00 pm | 3.00h | Science Building-SC176 | 115 | Jinling Zhang ; |
| EEE108 | Jinling Zhang | 12-Jun | Tue | 2:00 pm | 3.00h | Science Building-SD154 | 60 | Derek Paul Gray ; |
| EEE108 | Jinling Zhang | 12-Jun | Tue | 2:00 pm | 3.00h | Science Building-SD114 | 46 | Shaofeng Lu ; |

2017-18-S2 final exam timetable on e-Bridge



## This Friday – No Class

### Module Feedback Questionnaires (MQs)

- The MQs will be live from Monday, 21st May to Sunday, 3rd June, Weeks 13-14.
- You will be able to access the MQs in two ways:
  - ✓ You will receive emails and reminders of the links directly to your MQ.
  - ✓ You can also fill-out MQ via the ICE MQ page.
- Please fill out the questionnaires.
- Your feedback will help us to improve our TL.



Thanks for your attendance and

**Good Luck!**