Electronics Engineering

Basic Electrical Engineering

Comprehensive Theory

with **Solved Examples** and **Practice Questions**

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Contents

Basic Electrical Engineering

Chapter 5

Synchronous Machines 155-200

Chapter 6

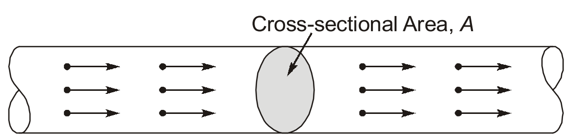
Basics of Power Plant and Batteries 201-242

CHAPTER 1

Electromagnetism

1.1 Electric Current

Electric current may be defined as the time rate of net motion of an electric charge across a cross-sectional area. A random motion of electrons in a metal does not constitute a current unless there is a net transfer of charge with time



i.e., electric current, i = Rate of transfer of electric charge

$$= \frac{\text{Quantity of electric charge transferred during a given time duration}}{\text{Time duration}}$$

$$= \frac{dQ}{dt}$$

Coulomb is the practical as well as SI unit for measurement of electric charge. One coulomb is approximately equal to sum of 624×10^{16} electrons charge.

Since current is the rate of flow of electric charge through a conductor and coulomb is the unit of electric charge, the current may be specified in coulombs per second or Ampere.

1.2 Electromotive Force and Potential Difference

Electromotive force (emf) is the force that causes an electric current to flow in an electric circuit while the potential difference between two points in an electric circuit is that difference in their electrical state which tends to cause flow of electric current between them.

Volt is a unit of electromotive force as well as potential difference in practical as well as in SI system of units.

The volt is defined as that potential difference between two points of a conductor carrying a current of one ampere when the power dissipated between these points is equal to one watt.

1.3 Resistance

Resistance may be defined as that property of a substance which opposes (or restricts) the flow of an electric current (or electrons) through it.

The SI unit of resistance is ohm (Ω), which is defined as resistance between two points of a conductor when a potential difference of one volt, applied between these points, produces in this conductor a current of one ampere, the conductor not being a source of any emf.

For insulators having high resistance, much bigger units kilo ohm or kΩ(10^3 ohm) and mega ohm or MΩ (10^6 ohm) are used. In case of very small resistances smaller units like milli-ohm (10^{-3} ohm) or micro ohm (10^{-6} ohm) are employed.

1.4 OHM's Law

The current flowing through a conductor is directly proportional to the potential difference across the ends of the conductor and inversely proportional to the conductor resistance. This relation was discovered by German physicist George Simon Ohm and so it is known as Ohm's law.

If I is the current flowing through a conductor of resistance R across which a potential difference V is applied then according to Ohm's law

$$I \propto V \text{ and } I \propto \frac{1}{R} \text{ or } I \propto \frac{V}{R} \text{ or } I = \frac{V}{R}$$

where V is in volt. R is in ohm and I is in ampere.

Ohm's law may be defined as follows:

Physical state i.e., temperature etc. remaining the same, the current flowing through a conductor is directly proportional to the potential difference applied across its ends.

or

The ratio of potential difference applied across a conductor and current flowing through it remains constant provided physical state i.e., temperature etc. of the conductor remains unchanged.

i.e. $$\frac{V}{I} = \text{constant} = R$$

where R is known as the resistance of the conductor.

Ohm's law may be alternatively expressed as

$$V = IR$$

Ohm's law cannot be applied to circuits consisting of electronic tubes or transistors because such elements are not bilateral i.e., they behave in different way when the direction of flow of current is reversed as in case of a diode. Ohm's law also cannot be applied to circuits consisting of nonlinear elements such as powdered carbon, thyrite, electric arc etc. For example, for silicon carbide, the relationship between applied voltage (for potential difference) V and current flowing I is given as $V = KI^m$ where K and m are constants and m is less than unity.

1.5 SI System of Units

SI stands for "System International d' Unites" in French. This abbreviation is now adopted by the International Standardising Organization as the abbreviated name of this new system of units in all languages.

The SI system is a comprehensive, logical and coherent system, designed for use in all branches of science, engineering and technology.

This system derives all the units from the following seven base units.

Quantity	Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Intensity of electric current	ampere	A
Thermodynamic temperature	Kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

The SI system besides seven base units, has following supplementary units.

Quantity	Unit	Symbol
Plane angle	radian	rad
Solid angle	steradian	sr

Recommended prefixes for formation of multiples and submultiples of units are given below:

Multiple	Prefix	Multiple	Prefix
10	deca	10^{-1}	deci
10^2	hecto	10^{-2}	centi
10^3	kilo (K)	10^{-3}	milli (*m*)
10^6	mega (M)	10^{-6}	micro (μ)
10^9	giga (G)	10^{-9}	nano (*n*)
10^{12}	tera (T)	10^{-12}	pico (*p*)

1.6 Work, Power and Energy

Work : Work is said to be done by or against a force, when its point of application moves in or opposite to the direction of the force and is measured by the product of the force and the displacement of the point of application in the direction of force.

i. e., Work done, $W = \text{Force } [F] \times \text{distance } [d]$

The SI or MKS unit of work is the joule, which is defined as the work done when a force of one newton acts through a distance of one metre in the direction of the force. Hence, if a force F acts through distance d in its own direction,

$$W = F\,[\text{newtons}] \times d\,[\text{metres}] = Fd \text{ joules}$$

Power : Power is defined as the rate of doing work or the amount of work done in unit time.

The MKS or SI unit of power is the joule/second or watt. In practice, the watt is often found to be inconveniently small and so a bigger unit, the kilowatt is frequently used.

$$1 \text{ kilowatt} = 1{,}000 \text{ watts}$$

Energy : Energy is defined as the capacity of doing work. Its units are same as those of work, mentioned above. If a body having mass m, in kg, is moving with velocity v, in metres/second,

$$\text{Kinetic energy} = \frac{1}{2}mv^2 \text{ J}$$

If a body having mass m, in kg, is lifted vertically through height h, in metres, and if g is the gravitational acceleration, in metres/second^2 in that region, potential energy acquired by the body

$$= \text{Work done in lifting the body} = mgh \text{ joule}$$

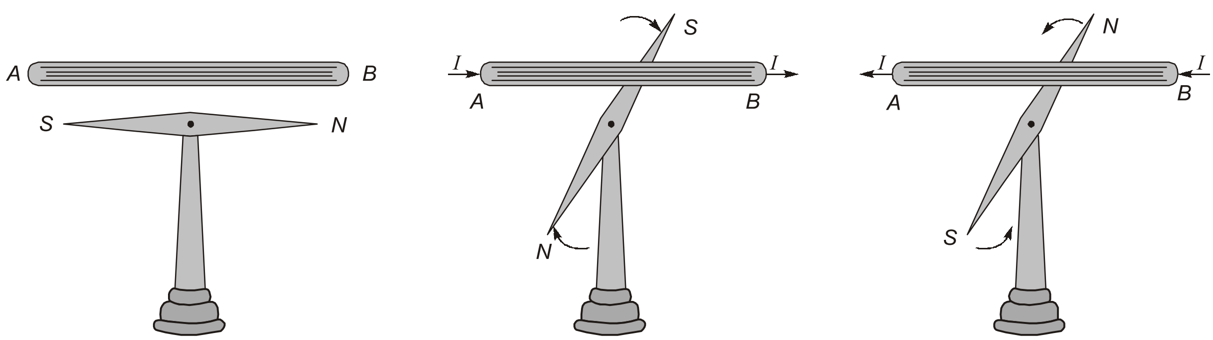
As already stated, in SI system the unit of energy of all forms is joule. Bigger unit of energy is mega joules (MJ) where 1 MJ = 10^6 J.

Calorie : It is the amount of heat required to raise the temperature of one gram of water through 1°C.

$$1 \text{ calorie} = 4.18 \text{ J} = 4.2 \text{ J}$$

1.7 Magnetic Field due to a Current Carrying Conductor

In 1819 it was discovered by a Danish Physicist, Hans Christian Oersted that an electric current is always accomplished by certain magnetic effects.

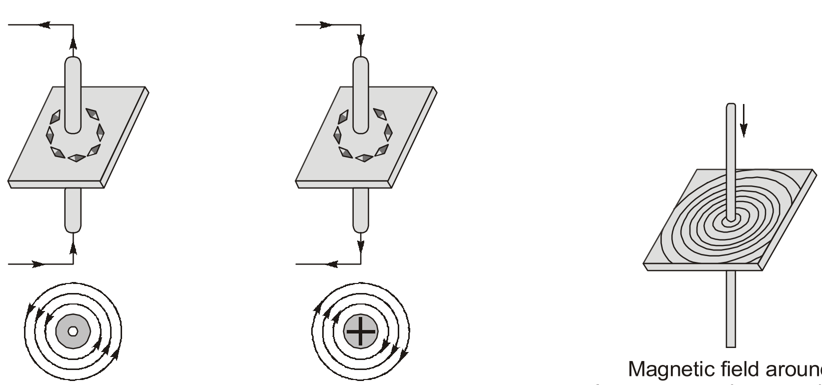


(a) No current flow **(b) Current flowing from *A* to *B*** **(c) Current flowing from *B* to *A***

Oersted found that when current is passed through a conductor placed above the magnetic needle, the needle turns in a certain direction, as shown in figures above. He also found that when the direction of flow of current is reversed the magnetic needle also deflects in opposite direction.

Further investigation showed that the field around the current carrying conductor consists of lines of force, which encircles the conductor. It can be proved experimentally by passing a current carrying conductor AB in the card board and plotting the field with the help of magnetic needle on it, as shown in figures below.

It is observed that when the current is passed through conductor in upward direction, the direction of lines of force is counterclockwise direction (observed from the top of the conductor) and when the current is passed through the conductor in downward direction, the direction of lines of force is clockwise (observed from the top of the conductor).



(d) **(e)** Magnetic field around A current carrying counductor

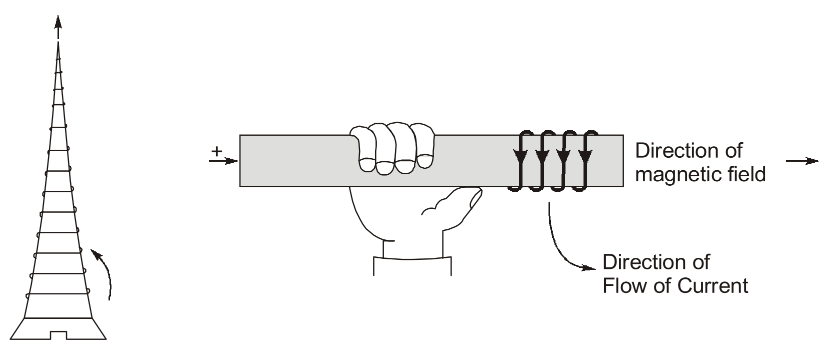
The properties of the lines of magnetic induction around a current carrying conductor are summarized as below:

(i) Lines of magnetic induction are circles, symmetrical about, and concentric with, the axis of the conductor.
(ii) The spacing between the lines of induction decreases as we move closer to the conductor.
(iii) The direction of lines of magnetic induction depends on the direction of flow of current through the conductor.
(iv) Magnetic induction or flux density depends upon the strength (or magnitude) of the current flowing through the conductor.

1.8 Determination of Direction of Magnetic Field Around a Current Carrying Conductor

The direction of lines of force (magnetic field) around a straight current carrying conductor may be determined by any of the following rules :

1. **Corkscrew Rule :** If the right handed corkscrew is held with its axis parallel to the conductor pointing the direction of flow of current and the head of the screw is rotated in such a direction that the screw moves in the direction of flow of current then the direction in which the head of screw is rotated, will be the direction of magnetic lines of force.
2. **Right Hand Rule :** If the current carrying conductor is held in right hand by the observer so that it is encircled by fingers stretching the thumb at right angle to the fingers in the direction of flow of current then finger tips will point the direction of magnetic lines of force, as shown in figure (b).



(a) Corkscrew Rule **(b) Right hand rule**

1.9 Magnetic Field due to a Circular Loop

If a single turn wire carrying current is bent in the form of a loop (or ring) as shown in figure. The lines of magnetic induction around it will be concentric circles, leaving the plane of the loop (or ring) on one side and entering on the other. The loop acts as the true magnet having north and south poles.

The direction of magnetic field may be determined by applying either of the two rules namely (i) right hand rule or (ii) corkscrew rule.

Example 1.1 A laminated soft iron ring of relative permeability 1000 has a mean circumference of 800 mm and a cross-sectional area 500 mm². A radial air-gap of 1 mm width is cut in the ring which is wound with 1000 turns. Calculate the current required to produce an air-gap flux of 0.5 mWb if leakage factor is 1.2 and stacking factor 0.9. Neglect fringing.

Solution:

$$\text{Total AT reqd.} = \Phi_g S_g + \Phi_i S_i = \frac{\Phi_g l_g}{\mu_0 A_g} + \frac{\Phi_i l_i}{\mu_0 \mu_r A_i B}$$

Now, air-gap flux $\Phi_s = 0.5\text{ mWb} = 0.5\times 10^{-3}$ Wb, $l_g = 1\text{ mm} = 1\times 10^{-3}$ m; $A_g = 500\text{ mm}^2 = 500\times 10^{-6}\text{ m}^2$

Flux in the iron ring, $\Phi_i = 1.2\times 0.5\times 10^{-3}$ Wb

Net cross-sectional area $= A_i \times$ stacking factor $= 500\times 10^{-6}\times 0.9\text{ m}^2$

$$\therefore \quad \text{Total AT reqd.} = \frac{0.5\times 10^{-3}\times 1\times 10^{-3}}{4\pi\times 10^{-7}\times 500\times 10^{-6}} + \frac{1.2\times 0.5\times 10^{-3}\times 800\times 10^{-3}}{4\pi\times 10^{-7}\times 1000\times (0.9\times 500\times 10^{-6})}$$

$$\therefore \quad I = \frac{1644}{1000} = \mathbf{1.64\ A}$$

Example 1.2 A ring has a diameter of 21 cm and a cross-sectional area of 10 cm². The ring is made up of semicircular sections of cast iron and cas steel, with each joint having a reluctance equal to an air-gap of 0.2 mm. Find the ampere-turns required to produce a flux of 8 × 10⁻⁴ Wb. The relative permeability of cast steel and cast iron are 800 and 166 respectively. Neglect fringing and leakage effects.

Solution:

$$\Phi = 8\times 10^{-4}\text{ Wb}$$

$$A = 10\text{ cm}^2 = 10^{-3}\text{ m}^2$$

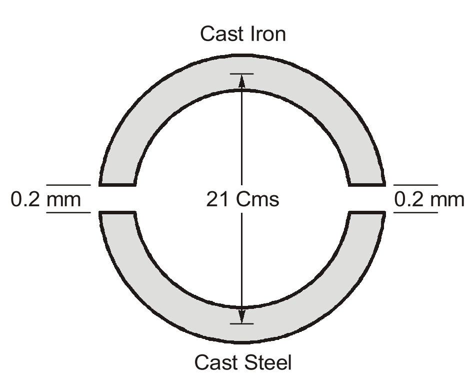
$$B = 8\times 10^{-4}/10^{-3} = 0.8\text{ Wb/m}^2$$

Air gap $\quad H = B/\mu_0 = 0.8/4\pi\times 10^{-7} = 6.366\times 10^{5}$ AT/m

Total air-gap length $= 2\times 0.2 = 0.4\text{ mm} = 4\times 10^{-4}$ m

$\therefore \quad$ AT required $= H\times l = 6.366\times 10^{5}\times 4\times 10^{-4} = 255$

Cast Steel Path



$$H = \frac{B}{\mu_0 \mu_r} = \frac{0.8}{4\pi \times 10^{-7} \times 800} = 796 \text{ AT/m}$$

$$\text{Path} = \pi \frac{D}{2} = 21 \frac{\pi}{2} = 33 \text{ cm} = 0.33 \text{ m}$$

$$\text{AT required} = H \times l = 796 \times 0.33 = 263$$

Cast Iron Path,

$$H = \frac{0.8}{4\pi \times 10^{-7} \times 166} = 3835 \text{ AT/m; path} = 0.33 \text{ m}$$

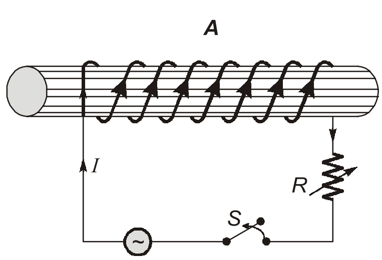
$$\text{At required} = 3835 \times 0.33 = 1265$$

$$\text{Total At required} = 255 + 263 + 1265 = \mathbf{1783\ AT}$$

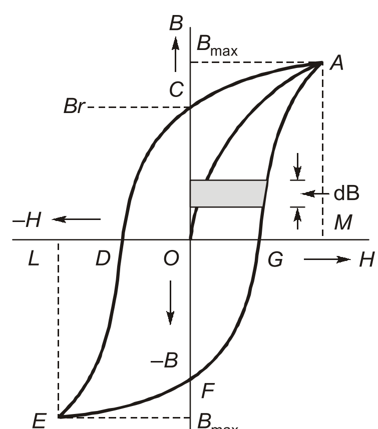
1.20 Magnetic Hysteresis

It may be defined as the lagging of magnetisation or induction flux density (B) behind the magnetising force (H). Alternatively, it may be defined as that quality of a magnetic substance, due to which energy is dissipated in it, on the reversal of its magnetism.

Let us take an unmagnetised bar of iron AB and magnetise it by placing it within the field of a solenoid, shown in figure (a). The field H (= NI/l) produced by the solenoid is called the magnetising force. The value of H can be increased or decreased by increasing or decreasing current through the coil. Let H be increased in steps from zero up to a certain maximum value and the corresponding values of flux density (B) be noted. If we plot the relation between H and B, a curve like OA, as shown in figure, is obtained. The material becomes magnetically saturated for $H = OM$ and has at that time a maximum flux density of B_{max} established through it.



(a)



(b)

If H is now decreased gradually (by decreasing solenoid current), flux density B will not decrease along AO, as might be expected, but will decrease less rapidly along AC. When H is zero, B is not but has a definite value $B_r = OC$. It means that on removing the magnetising force H, the iron bar is not completely demagnetised. This value of B (= OC) measures the **retentivity** or **remanence** of the material and is called the **remanent** or **residual flux density B_r**.

To demagnetise the iron bar, we have to apply the magnetising force in the reverse direction. When H is reversed (by reversing current through the solenoid), then B is reduced to zero at point D where $H = OD$. This value of H required to wipe off residual magnetism is known as coercive force (H_c) and is a measure of the coercivity of the material.

Solution :

$$L = \frac{\mu_0 N^2 A}{l_g} = \frac{4\pi \times 10^{-7} \times (10^3)^2 \times 10 \times 10^{-4}}{1 \times 10^{-3}} = 1.26 \text{ H}$$

(i) Here, $dI/dt = 25$ A/s, $dL/dt = 0$ because armature is stationary.

$$\therefore \quad \frac{dE}{dt} = LI\frac{dI}{dt} = 1.26 \times 10 \times 10^{-3} \times 15 = 0.315 \text{ W}$$

(ii) Here, $dL/dt = 100$ H/s, $dI/dt = 0$ because current is constant

$$\therefore \quad \frac{dE}{dt} = \frac{1}{2}I^2\frac{dL}{dt} = \frac{1}{2}(20 \times 10^{-3})^2 \times 100 = 0.02 \text{ W}$$

Student's Assignment

Q.1 **Assertion (A) :** In an electric circuit, the current is due to the presence of electromotive force.
Reason (R) : In a magnetic circuit, the magnetic flux is due to the presence of a magnetomotive force.
(a) Both A and R are true and R is a correct explanation of A.
(b) Both A and R are true but R is not a correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

Q.2 **Assertion (A):** Leakage flux has a path dominated through the surrounding air.
Reason (R): Leakage flux may be defined as that flux which does not follow the intended path in a magnetic circuit.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Q.3 A conductor 20 cm long moves at right angle to its length at a constant speed of 30 m/s in a uniform magnetic field of flux density 1.2 T. The emf induced in case the conductor motion is normal to the field flux is
(a) 0 volt (b) 28.8 volt
(c) 7.2 volt (d) 14.4 volt

Q.4 A magnetic circuit with relative permeability of 100 has a core cross-sectional area of 5 cm^2 and mean core length of 25 cm. The coil has 120 turns with an mmf of 1000 AT. The magnetic core flux is
(a) 0.75 mWb (b) 1 mWb
(c) 0.05 mWb (d) 0.25 mWb

Q.5 Match **List-I** (Magnetic quantities) with **List-II** (Units) and select the correct answer using the codes given below the lists:

	List-I		List-II
A.	Permeability	**1.**	Wb
B.	Magnetic field intensity	**2.**	Wb/m^2
C.	Magnetic flux	**3.**	H/m
D.	Magnetic flux density	**4.**	Amp.-turns/m

Codes:

	A	B	C	D
(a)	4	3	1	2
(b)	3	4	1	2
(c)	4	2	3	1
(d)	3	1	2	4

Q.6 "In all cases of electromagnetic induction, an induced voltage will cause a current to flow in a closed circuit in such a direction that the magnetic field which is caused by that current will oppose the change that produces the current", is the original statement of

(a) Lenz's Law
(b) Fleming's law of induction
(c) Ampere's circuital law
(d) Faraday's law of magnetic induction

Q.7 Match **List-I (Electric Circuit)** with **List-II (Magnetic Circuit)** and select the correct answer using the codes given below the lists:

List-I	List-II
A. Current	1. Magnetic flux density
B. Conductivity	2. Magnetic field intensity
C. Electric field intensity	3. Magnetic flux
D. Current density	4. Permeability

Codes:

	A	B	C	D
(a)	2	4	3	1
(b)	3	4	2	1
(c)	2	3	4	1
(d)	3	1	2	4

Q.8 One 800-turn flat coil with an area of 5×10^{-2} m^2 is rotating in a magnetic field of flux density 60 mWb/m^2 at 1500 rpm. The value of induced emf in the coil if the plane of the coil is parallel to the field is
(a) 375 V
(b) 288 V
(c) 392 V
(d) 377 V

Answer Key :

1. (b) **2.** (a) **3.** (c) **4.** (d) **5.** (b)
6. (a) **7.** (b) **8.** (d)

Student's Assignments Explanations

1. (b)

$$I = \frac{\text{EMF}}{R} \text{ (for an electric circuit)}$$

$$\phi = \frac{\text{MMF}}{\text{Redactance}}$$

(for a magnetic circuit)

2. (a)

3. (c)

Given, $\theta = 90°$

$\therefore$ emf induced $= B\,l\,v \sin\theta$
$= 1.2 \times 0.2 \times 30 \times \sin 90°$
$= 7.2$ volt

4. (d)

Given, $\mu_r = 100$, $a = 5$ cm^2, $l = 25$ cm, $N = 120$ turns, NI = MMF = 1000 AT

We know that,

$$\text{Flux} = \frac{\text{MMF}}{Rl}$$

$$= \frac{NI}{\left(\frac{l}{\mu_0\mu_r A}\right)} = \frac{NI \cdot \mu_0\,\mu_r A}{l}$$

or, $$\text{Flux} = \frac{1000 \times 4\pi \times 10^{-7} \times 100 \times 5 \times 10^{-4}}{25 \times 10^{-2}}$$

$$= \frac{4\pi}{5} \times 10^{-4} = 0.25 \text{ mWb}$$

5. (b)

$$H = \frac{NI}{l}\left(\frac{\text{Ampere-turn}}{\text{metre}}\right)$$

$$\phi = \text{B.A.}$$

or, $$B = \frac{\phi}{A} \text{ (Wb/m}^2\text{)}$$

ϕ has a unit of Wb; permeability, μ has unit of Henry/m.

6. (a)

7. (b)

8. (d)

Emf induced, $e = N\phi\omega$

Here, $\phi = B \times A$
$= 60 \times 10^{-3} \times 5 \times 10^{-2}$
$= 3 \times 10^{-3}$ Wb

And, $$\omega = \frac{2\pi}{60}N = \frac{2\pi \times 1500}{60} = 50\,\pi \text{ rad/s}$$

Given, N = Number of turns = 800

So, emf induced,

$$e = 800 \times 3 \times 10^{-3} \times 50\,\pi = 377 \text{ volt}$$

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