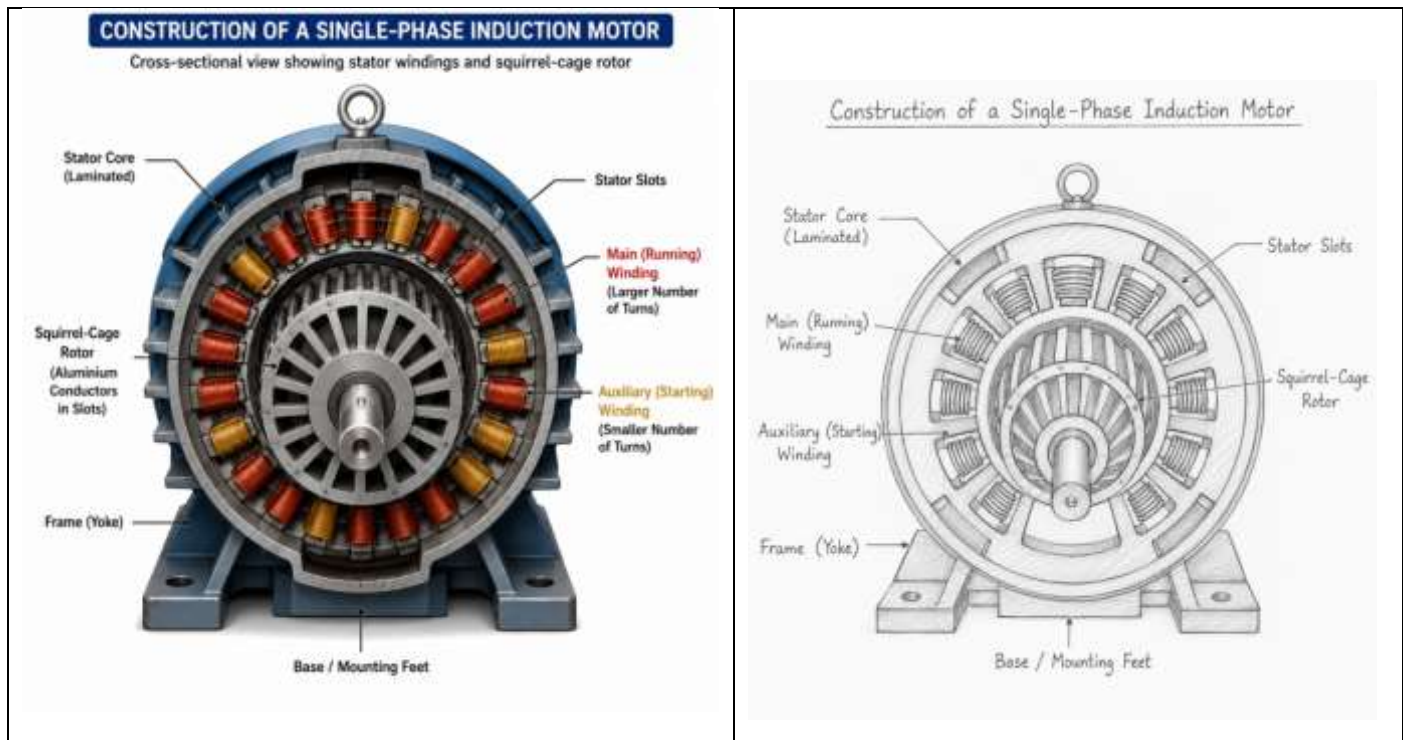


SINGLE-PHASE INDUCTION MOTORS

CONSTRUCTION OF A SINGLE-PHASE INDUCTION MOTOR

A single-phase induction motor is an AC machine which converts single-phase electrical power into mechanical power, and is the most commonly used motor in domestic and small industrial applications such as fans, pumps, washing machines, refrigerators, and mixers, on account of its simplicity, robustness, and the widespread availability of a single-phase AC supply. Its construction closely resembles that of a three-phase induction motor, consisting of two principal parts: the stator and the rotor.



Stator

The stator is the stationary part of the motor and consists of a laminated cylindrical frame (core) with slots on its inner periphery to accommodate the stator winding.

- **Stator Core:** Built up of thin laminations of high-grade silicon steel, insulated from one another to reduce eddy current and hysteresis losses. It is fixed inside an outer frame, usually of cast iron or aluminium alloy.
- **Stator Winding:** Unlike a three-phase induction motor, the single-phase stator normally carries two separate windings occupying the same slots but displaced from each other by 90 electrical degrees: the Main (Running) Winding, made of heavier gauge wire with more turns and higher inductance, which remains connected throughout the operation of the motor; and the Auxiliary (Starting) Winding, made of thinner wire with fewer turns and higher resistance, which is used only to help the motor start and, in many designs, is disconnected from the supply once the motor picks up speed (typically by a centrifugal switch).

- In many practical designs, a capacitor is connected in series with the auxiliary winding to improve the phase difference between the currents in the two windings, and hence to improve starting performance (discussed further under Types).

Rotor

The rotor is almost universally of the squirrel-cage type in single-phase induction motors, owing to its simplicity, ruggedness, and low cost.

- **Rotor Core:** A cylindrical laminated core of silicon steel, keyed to the shaft, with slots on its outer periphery.
- **Rotor Bars and End Rings:** Copper or aluminium bars are placed in the rotor slots and short-circuited at both ends by copper or aluminium end-rings, forming a closed cage circuit. In small motors, the entire rotor cage (bars and end rings) is often die-cast in aluminium in a single operation.
- The rotor has no external electrical connection; current is induced in the rotor bars purely by electromagnetic induction from the stator field, exactly as in a three-phase squirrel-cage induction motor.

Other Components

- **Shaft:** Made of mild steel, transmits mechanical output power and is supported by bearings at both ends.
- **Bearings:** Ball or roller bearings (or, in small motors, sleeve bearings) that support the rotor shaft and permit free rotation with minimum friction.
- **End Shields (End Covers):** Fitted at both ends of the frame, they house the bearings and maintain the rotor centrally within the stator bore, ensuring a uniform air gap.
- **Centrifugal Switch:** Fitted in many single-phase motors (particularly split-phase and capacitor-start types) to automatically disconnect the auxiliary/starting winding once the rotor reaches about 70–80% of its synchronous speed.

PRINCIPLE OF OPERATION

When a single-phase AC supply is given to the main stator winding alone, the current produces a magnetic field that is not rotating but merely alternating — that is, it is a pulsating field fixed in space but varying sinusoidally in magnitude and reversing direction twice every cycle. This is fundamentally different from a three-phase stator winding, which produces a smoothly rotating magnetic field. This basic difference explains why a single-phase induction motor is not inherently self-starting, and its operation is best understood through the Double Revolving Field Theory.

Double Revolving Field Theory

The Double Revolving Field Theory states that a single alternating (pulsating) magnetic field can be resolved into two magnetic fields of equal magnitude (each equal to half the maximum value of the alternating field), rotating in opposite directions at synchronous speed.

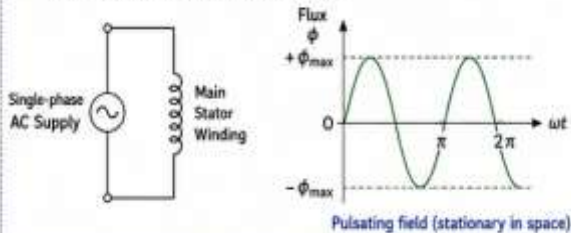
$$\text{Alternating field} = \text{Forward-rotating field (Nf)} + \text{Backward-rotating field (Nb)}$$

- The forward field rotates in the same direction as the (eventual) rotor rotation, at synchronous speed N_s .
- The backward field rotates at the same synchronous speed but in the opposite direction.
- At standstill, the rotor is cut equally by both fields, so each field induces an equal and opposite torque in the rotor, and the two torques exactly cancel — the net starting torque is zero. This is precisely why a single-phase induction motor with only a main winding energised cannot start on its own.

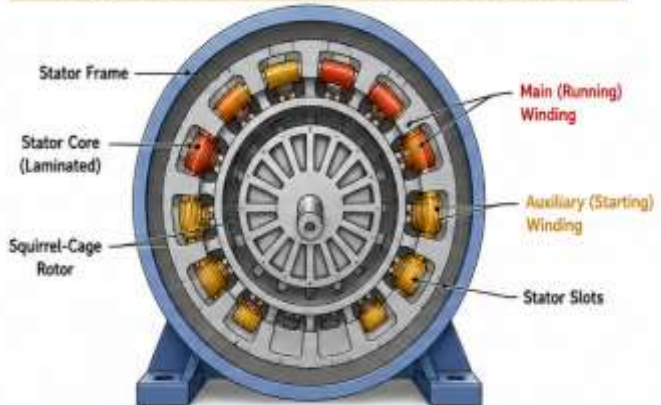
PRINCIPLE OF OPERATION OF SINGLE-PHASE INDUCTION MOTOR

PULSATING MAGNETIC FIELD PRODUCED BY SINGLE-PHASE AC SUPPLY

Single-phase AC supply to main stator winding produces a pulsating magnetic field which alternates in magnitude and reverses direction twice every cycle. It is not a rotating field.

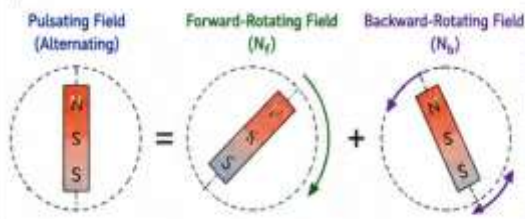


CROSS-SECTIONAL VIEW OF SINGLE-PHASE INDUCTION MOTOR



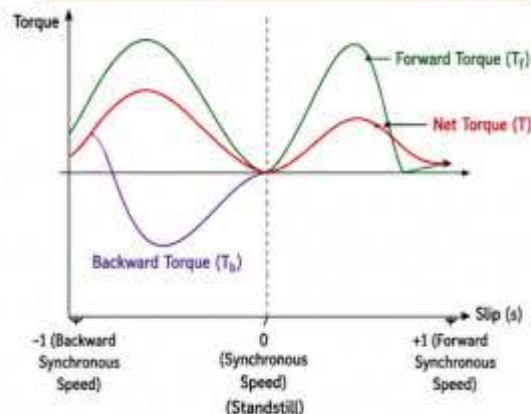
DOUBLE REVOLVING FIELD THEORY

A pulsating magnetic field can be resolved into two rotating magnetic fields of equal magnitude, rotating in opposite directions at synchronous speed.



- Both fields have equal magnitude (each = half of the pulsating field).
- Both rotate at synchronous speed (N_s) in opposite directions.

RESULTANT TORQUE-SLIP CHARACTERISTIC



- Forward field produces positive torque in the forward direction.
- Backward field produces torque in the opposite direction.
- At standstill ($s = 1$ for both fields), the torques are equal and opposite, so net starting torque is zero.
- Hence, a single-phase induction motor with only main winding cannot start by itself.

Behaviour Once Rotation is Established

If the rotor is given an initial push in either direction by some external means (or by an auxiliary starting arrangement, as described under Types), it will continue to accelerate in that direction and run up to a stable operating speed close to synchronous speed. This happens because, once the rotor rotates, the slip with respect to the forward field decreases while the slip with respect to the backward field increases towards 2. The rotor impedance and induced currents due to the two fields become unequal, and the forward-field torque comes to dominate heavily over the (now much reduced) backward-field torque, giving a substantial net torque in the direction of rotation. The motor therefore continues to run, even though it could not start, by itself, from rest.

Necessity of a Starting Mechanism

Since the net starting torque with only the main winding is zero, every practical single-phase induction motor must include some auxiliary means of producing an initial rotating (or at least unbalanced two-phase-like) field at standstill, so as to develop a net starting torque. This is achieved in practice by adding a second (auxiliary) winding displaced in space from the main winding and carrying a current displaced in time-phase from the

main winding current — the various methods of achieving this time-phase displacement give rise to the different types of single-phase induction motors discussed in Topic 3.

Cross-Field Theory (Alternative Explanation)

An alternative, equivalent explanation of the working of a single-phase induction motor once it is rotating is provided by the Cross-Field Theory. According to this theory, the main winding produces a pulsating flux along its axis; the rotor currents induced by this flux, combined with the rotor's rotation, produce a second flux along an axis at 90 electrical degrees to the main winding axis (the cross-field). The interaction between the main-winding flux and this cross-field flux, both varying with time, is what maintains the running torque of the motor. Both theories — double revolving field and cross-field — arrive at consistent conclusions regarding the running performance of the motor, and are used according to convenience of analysis.

TYPES OF SINGLE-PHASE INDUCTION MOTORS

Single-phase induction motors are classified mainly according to the method used to produce the starting torque required to overcome the zero net torque at standstill (as explained in Topic 2). The important types are discussed below.

Split-Phase (Resistance-Start) Induction Motor

This motor has two stator windings — a main winding of low resistance and high inductive reactance, and an auxiliary (starting) winding of comparatively high resistance and low reactance — connected in parallel across the single-phase supply, displaced from each other by 90 electrical degrees in space.

- Because the auxiliary winding is more resistive and less inductive than the main winding, the current in the auxiliary winding leads the current in the main winding by a small angle (typically 25° – 30°) in time phase.
- This time-phase difference, combined with the 90° space displacement of the two windings, produces an unbalanced, roughly rotating magnetic field at standstill, sufficient to develop a moderate starting torque.
- Once the motor reaches about 70–80% of synchronous speed, a centrifugal switch disconnects the auxiliary winding, and the motor continues to run on the main winding alone.
- Characteristics: Low to moderate starting torque, high starting current, low cost, simple construction.
- Applications: Fans, blowers, grinders, washing machines, and other loads requiring a moderate starting torque.

[Diagram: Split-phase motor circuit showing main winding, auxiliary winding, and centrifugal switch — draw and label neatly in the answer sheet]

Capacitor-Start Induction Motor

This motor is similar in construction to the split-phase motor, but a capacitor is connected in series with the auxiliary winding (along with the centrifugal switch).

- The capacitor causes the current in the auxiliary winding to lead the supply voltage, producing a much larger phase difference (close to 90°) between the currents in the main and auxiliary windings than in the plain split-phase motor.

- This closer approach to a true two-phase condition at standstill gives a much higher starting torque than the split-phase motor.
- As in the split-phase motor, the auxiliary winding (and the capacitor) is disconnected by a centrifugal switch once the motor approaches running speed.
- Characteristics: High starting torque, moderate starting current, slightly higher cost due to the capacitor.
- Applications: Compressors, pumps, refrigerators, air conditioners, and other loads requiring high starting torque.

[Diagram: Capacitor-start motor circuit showing main winding, auxiliary winding in series with starting capacitor and centrifugal switch — draw and label neatly in the answer sheet]

Capacitor-Start Capacitor-Run (Two-Value Capacitor) Motor

This design uses two capacitors: a starting capacitor of relatively large capacitance, connected in series with the auxiliary winding through a centrifugal switch to provide high starting torque; and a running capacitor of smaller capacitance, permanently connected in series with the auxiliary winding to improve the running power factor, efficiency, and torque smoothness while the motor is in normal operation.

- Gives both high starting torque (through the starting capacitor) and good running performance (through the running capacitor), combining the advantages of the capacitor-start motor and the permanent-capacitor motor.
- More expensive and complex than single-capacitor designs, owing to the additional capacitor and switch.
- Applications: Compressors and other loads demanding both high starting torque and efficient, quiet continuous running.

Permanent-Split Capacitor (PSC) Motor

In this type, a single capacitor of suitable (moderate) capacitance is permanently connected in series with the auxiliary winding, and there is no centrifugal switch — the auxiliary winding and capacitor remain in the circuit at all times, both during starting and running.

- Simpler and more reliable than switched designs, since it has no centrifugal switch to wear out or fail.
- Gives a lower starting torque than a capacitor-start motor (since the capacitance is a compromise value, not optimised purely for starting), but smoother, quieter running, better power factor, and higher efficiency at running speed.
- Applications: Ceiling fans, small blowers, and other loads requiring low starting torque but smooth, quiet, continuous operation.

Shaded-Pole Induction Motor

This is one of the simplest and cheapest types of single-phase induction motor, used for very small power ratings (a few watts up to about 1/20 HP typically). It has salient (projecting) poles on the stator, each pole face split into two unequal segments; a copper short-circuited ring, called a shading coil or shading ring, encircles the smaller segment of each pole.

- The alternating flux produced by the main winding induces a current in the shading ring, which, by Lenz's Law, opposes the change of flux in the shaded portion of the pole, causing the flux in the shaded segment to lag the flux in the unshaded segment in time phase.

- This produces an effective shifting (from unshaded to shaded segment) of the magnetic field across the pole face, similar in effect to a rotating field, which is sufficient to produce a small starting torque, causing the rotor to start rotating from the unshaded towards the shaded pole segment.
- Characteristics: Very simple, extremely low cost, no centrifugal switch or capacitor required, but low starting torque, low efficiency, and low power factor.
- Applications: Small table fans, exhaust fans, hair dryers, record players, and other very light, low-power drives.

[Diagram: Shaded-pole motor showing salient pole with main winding and shading coil around a portion of the pole face — draw and label neatly in the answer sheet]

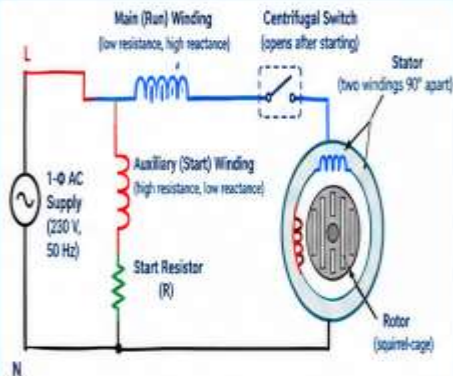
Repulsion Motor

A repulsion motor uses a rotor similar to a DC armature (with commutator and brushes) instead of a squirrel cage; the brushes are short-circuited on themselves rather than connected to an external supply. Torque is produced by the interaction of the stator's pulsating field with currents induced in the rotor winding through the commutator, the brush axis being set at an angle to the main field axis. Such motors provide high starting torque and were historically used in some applications requiring variable speed, but have been largely superseded by capacitor-type motors due to the maintenance requirements of the commutator and brushes.

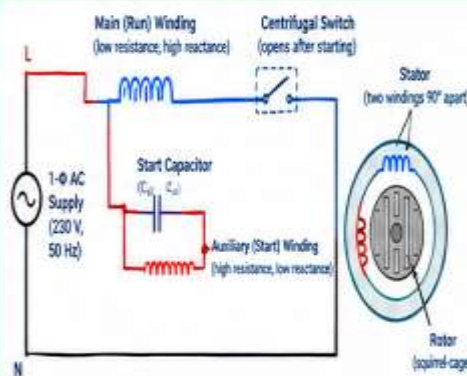
Draw all the diagrams if necessary each motors diagrams mentioned below

Single-Phase Induction Motors – Line Diagrams

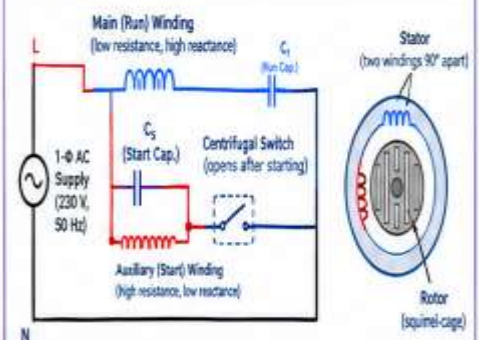
1. Split-Phase (Resistance-Start) Induction Motor



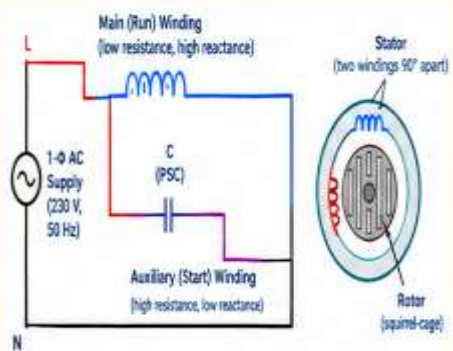
2. Capacitor-Start Induction Motor



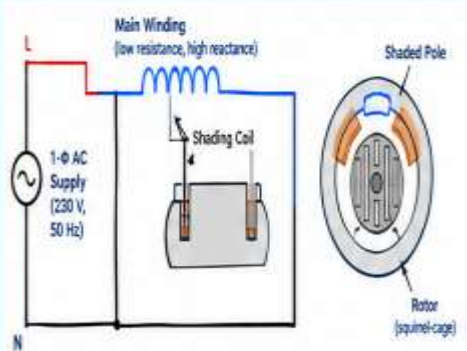
3. Capacitor-Start Capacitor-Run (Two-Value Capacitor) Motor



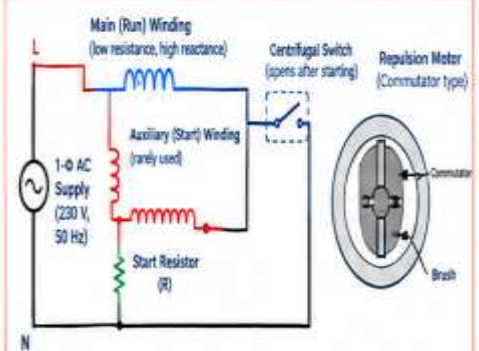
4. Permanent-Split Capacitor (PSC) Motor



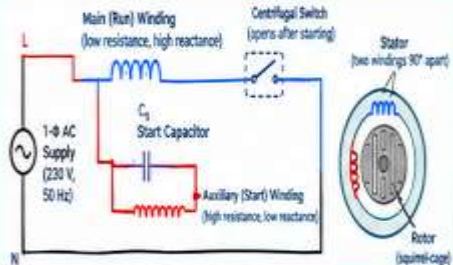
5. Shaded-Pole Induction Motor



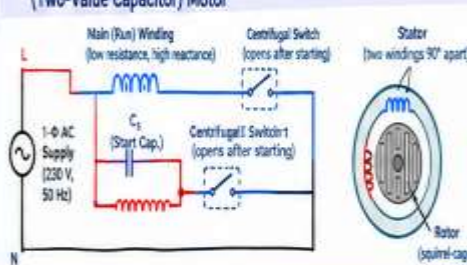
6. Repulsion Motor (Split-Phase / Resistance-Start)



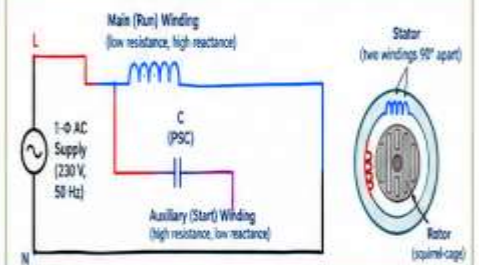
7. Capacitor-Start Induction Motor



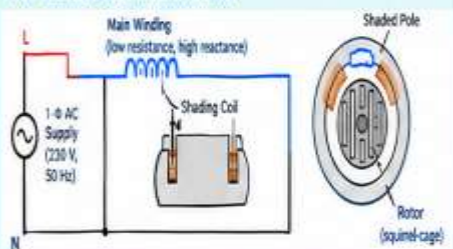
8. Capacitor-Start Capacitor-Run (Two-Value Capacitor) Motor



9. Permanent-Split Capacitor (PSC) Motor



10. Shaded-Pole Induction Motor



11. Repulsion Motor (Split-Phase / Resistance-Start)



Legend

