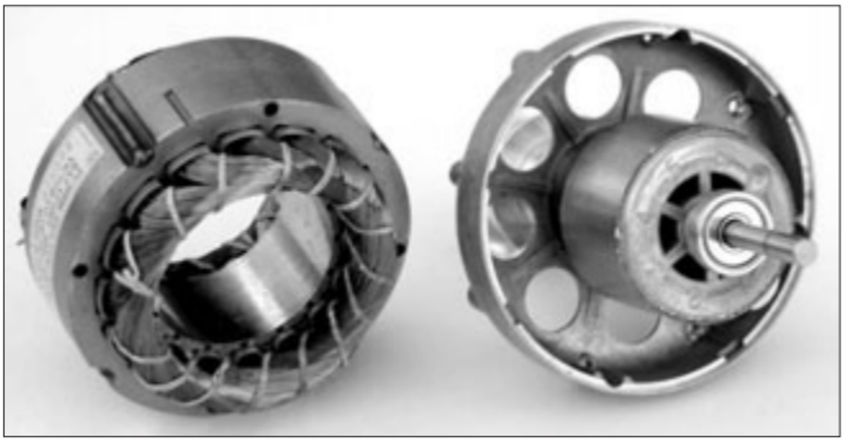
The photograph below shows parts of an AC electric motor. **3**

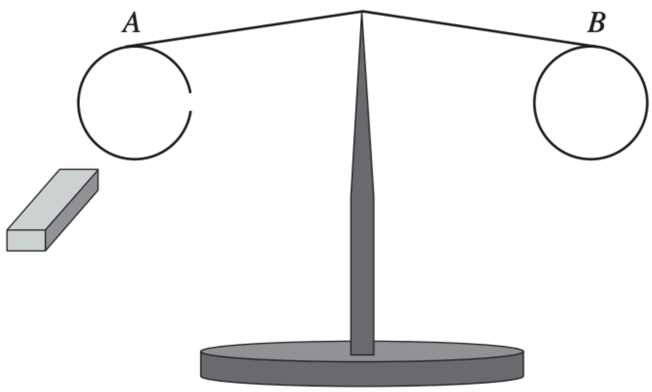


Describe the main features of this type of motor and its operation.

- In an AC induction motor, Faraday's law of electromagnetic induction is used. A rotating magnetic field is created by running AC current through three pairs of coils on the stator, with each coil out of phase with the other, so that the north and south pole progressively move around the motor.
- The rotor is a squirrel cage rotor, which consists of conducting bars attached to 2 end rings at either end, and this is placed in a cylindrical region with a rotating magnetic flux. The rotor is inside a laminated iron casing and mounted on an axle for easy rotation.
- The squirrel cage rotor experiences a change in magnetic flux, which induces an emf proportional to the rate of change of flux, by Faraday's law. By Lenz's law, the induced current has a direction such that the magnetic field due to the current opposes the change in magnetic flux that induced the current. These induced currents in the squirrel cage rotor experience a motor effect force ($F = IlB\, sin\,\theta$) and cause the squirrel cage to rotate in the same direction as the rotating magnetic field.
- The difference between the speed of the rotor and the rotating magnetic field is called the slip speed. The squirrel cage rotor always rotates a little slower than the magnetic field to experience a changing magnetic flux, inducing an emf and current.
- There are no moving parts (commutators and brushes) in contact with each other contributing to low maintenance and increased reliability.

Mod 6 – Question 17 (5 marks)

The diagram shows two rings *A* and *B*, connected to a balancing arm which swings freely on a pivot. Ring *A* has a split in it as shown. **5**

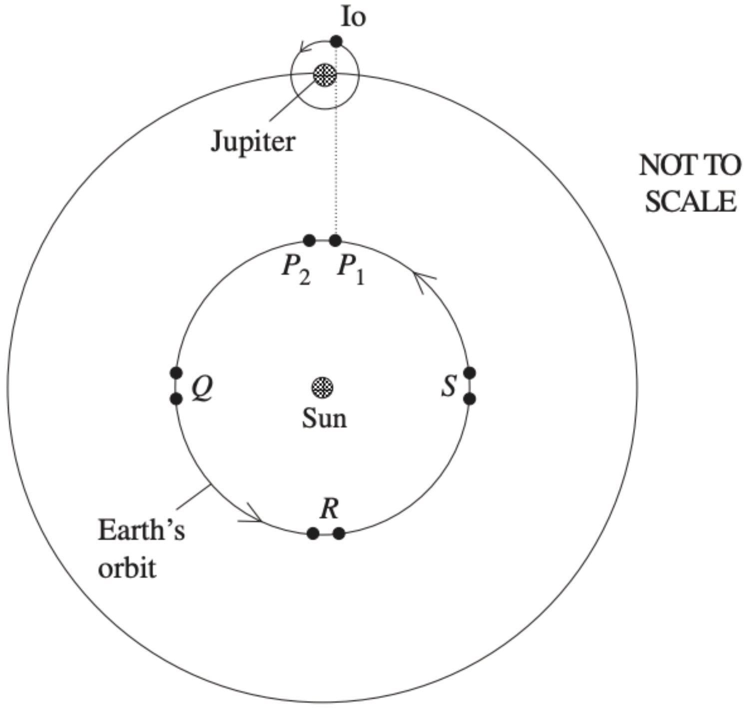


When a bar magnet is pushed into one of the rings, the whole balancing arm begins to rotate on the pivot. When the magnet is pulled out, the balancing arm begins to rotate in the opposite direction. When the magnet is pushed in and out of the other ring, the apparatus does not move at all.

Account for these observations using Lenz's Law and conservation of energy.

- When the magnet is pulled into ring B, there is an increasing magnetic flux through the circular area enclosed by ring B. This induces an emf proportional to the rate of change of flux, by Faraday's law ($\mathcal{E} = -N\frac{d\Phi_B}{dt}$).
- Since ring B is part of a complete circuit, an induced current will flow. The direction of the induced current is such that the magnetic field due to the current opposes the change in magnetic flux, by Lenz's law.
- The induced magnetic field will repel the magnet, to oppose the flux change. The magnet exerts an equal and opposite force on the ring by Newton's 3rd law. Hence, the balancing arm will rotate on the pivot.
- When the magnet is pulled out, there is a decreasing magnetic flux through the loop, inducing an emf and current. The induced magnetic field will now attract the magnet to oppose the flux change by Lenz's law, and exert a force on the magnet in the opposite direction compared to when the magnet was pushed.
- Hence, the force exerted by the magnet on the ring by Newton's third law is also in the other direction, causing the entire balancing arm to rotate in the other direction.
- When the bar magnet is pushed into and pulled out of ring A, there is a changing magnetic flux through ring A and an emf proportional to the rate of change of magnetic flux will be induced by Faraday's law.
- However, the gap in ring A means that it does not form a complete circuit, an induced current will not flow, and a magnetic field will not be induced. Hence, the balancing arm will not rotate.

In 1676, Ole Romer used indirect empirical evidence to estimate the speed of light at 2.2×10^8 m/s, with a diagram shown below.



He observed that the period of Io's orbit around Jupiter was measured to be longer during Q than during P_1 to P_2. Use the diagram to qualitatively explain how Romer's measurements allowed him to determine the speed of light.

4 marks

- Romer measured the period of Io's orbit around Jupiter to measure the speed of light. Romer measured the time between two successive eclipses of Io, to measure the Io's orbital period.
- Romer observed that when the Earth was moving away from Jupiter, the time between successive eclipses was longer. This corresponds to points Q on the diagram. When the Earth was moving towards Jupiter, the time between eclipses was less. This corresponds to S on the diagram.
- This is because the speed of light is finite, and when the Earth is moving away from Jupiter, light from Io must travel a greater distance to reach Earth. Conversely, when Earth is moving towards Jupiter, light from Io must travel a shorter distance to reach Earth.
- By calculating the time between eclipses of Io when the Earth is nearest to Jupiter (point P on the diagram, where the distance between Earth and Jupiter is changing negligibly), Romer calculated the orbital period of Io. From this, Romer calculated the number of eclipses during 6 months, and predicted the time that an eclipse should happen 6 months later at point R on the diagram.
- The eclipse started later than predicted by Romer. This is the time taken for light to travel a distance equal to the diameter of the Earth's orbit around the Sun. By dividing this distance by the time difference, Romer was able to calculate the speed of light.

Both Niels Bohr and de Broglie contributed to developing a model of the atom.

By analysing the evidence, justify the acceptance of de Broglie's model of the atom instead of Bohr's model at that time.

8 marks

- In the Bohr model of the atom, electrons in circular orbit around a nucleus exists in quantised, stable stationary states in which it does not emit any electromagnetic radiation.
- An electron transition between two stationary states will result in the emission or absorption of a photon, with energy equal to the energy difference between the two stationary states.
- The size of an allowed electron orbit is determined by a condition imposed on the electron's orbital angular momentum: $L = mvr = n\frac{h}{2\pi}$ (quantisation of angular momentum).
- However, Bohr's model could not provide a theoretical basis for why electrons do not lose energy in stationary states or justify the quantisation of angular momentum.
- De Broglie postulated that every moving particle has an associated matter wave given by $\lambda = \frac{h}{mv}$.
- Rather than visualising the electron as a particle in circular orbit around the nucleus, he thought of it as an electron matter wave that extends around the circle.
- The allowed Bohr orbits arise because the electron matter waves constructively interfere and form a standing wave that radiate no energy when an integral number of wavelengths fit around the circumference of the circular orbit, that is, $n\lambda = 2\pi r$. Combining this with $\lambda = \frac{h}{mv}$, $n\frac{h}{mv} = 2\pi r$ and $mvr = n\frac{h}{2\pi}$, hence, de Broglie's wave picture of electrons naturally leads to quantisation of angular momentum, and explains the stability of electrons.
- Davisson and Germer experimentally verified de Broglie's hypothesis, by shooting electrons into a nickel crystal. The intensity of the scattered electron beam as a function of the scattering angle θ resembled a diffraction pattern.
- They determined the wavelength of the electron waves using both diffraction equations and de Broglie's equation and found that the values were in agreement. Since diffraction is a wave phenomena, Davisson and Germer had provided experimental evidence in support of de Broglie's matter wave hypothesis.
- Thus de Broglie's model became the accepted model over Bohr's.

Astronomers combine mathematical models with observations to develop theories to describe the evolution of the observable universe. The Big Bang theory is the prevailing cosmological model that explains origin and subsequent large-scale expansion of the universe. Describe how the careful observation of the electromagnetic radiation from various sources gave evidence in support of the Big Bang Theory.

- The cosmic microwave background radiation provides experimental support for the Big Bang theory.
- The hot early universe was filled with blackbody radiation, and, at $t = 380{,}000$ years after the Big Bang, when the first neutral atoms formed, and the temperature was 3000 K, there were fewer charged particles such as protons and electrons to scatter the photons.
- This meant that these hot photons could travel mostly freely, and the universe became transparent for the first time. Before, the universe was opaque as light (photons) were scattered by charged particles and could not travel freely.
- These hot photons were cosmologically redshifted to longer wavelengths as the universe expanded, and are now detected in the microwave region, where the temperature of the universe is 2.725 K.
- When Penzias and Wilson first discovered the CMBR, they found that it was isotropic (same in all directions). That is, they detected nearly the same background intensity no matter which direction they pointed their antenna at the sky.
- This supports the inflationary epoch, which occurred from $t = 10^{-35} - 10^{-32}$ s after the Big Bang, where the universe expanded 10^{26} times in linear size, triggered by the separation of the strong nuclear force from the grand unified force.
- This rapid inflationary epoch is necessary to explain the isotropy and homogeneity of the CMBR.
- Furthermore, a critical part of the Big Bang theory of the universe is the expanding universe. Hubble observed the redshift of spectra from distant galaxies, and found that the further away a galaxy is, the more redshifted their spectra. The Doppler effect is a shift in wavelength if there is relative motion between observer and wave source. The spectral line from a receding source is shifted towards longer wavelengths (a redshift).
- By using the Doppler shift formula $\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$ where $\Delta\lambda = \lambda - \lambda_0 =$ wavelength shift, $\lambda_0 =$ wavelength if object was at rest and $v =$ recessional velocity of galaxies, Hubble determined a roughly proportional relationship between the recessional velocity of a galaxy and their distance away from us.
- Mathematically, $v = H_0 d$. If galaxies further away from us are moving away from us at a faster rate, it means that the universe is expanding, with the corollary that the universe expanded from a single point. This is because if we "play the film backwards" and reverse the direction of time, the expanding must've started from a single point, and with everything converging to a single point, the temperature must've been extremely high. Hence, Hubble's law is critical evidence supporting the Big Bang theory.