

QUESTIONS ON CHAPTER 6

- (a) Why did scientists once believe in the existence of the ether?
(b) Why was the concept eventually abandoned?
- Give a brief account of the Michelson–Morley experiment. Explain how the outcome of the experiment implied that the concept of absolute motion is meaningless.
- An atomic clock moves at 300 m s^{-1} for 24.0 hours as measured by an identical stationary clock. How many nanoseconds does the moving clock 'lose' compared with the stationary clock? (Make use of the approximation $(1 - x)^{-1/2} \approx 1 + \frac{1}{2}x$.) (Speed of light = $3.00 \times 10^8 \text{ m s}^{-1}$.)

- A star is 8 light-years away from the Earth. A rocket leaves Earth and travels to the star in 6 years as measured by a clock in the rocket.

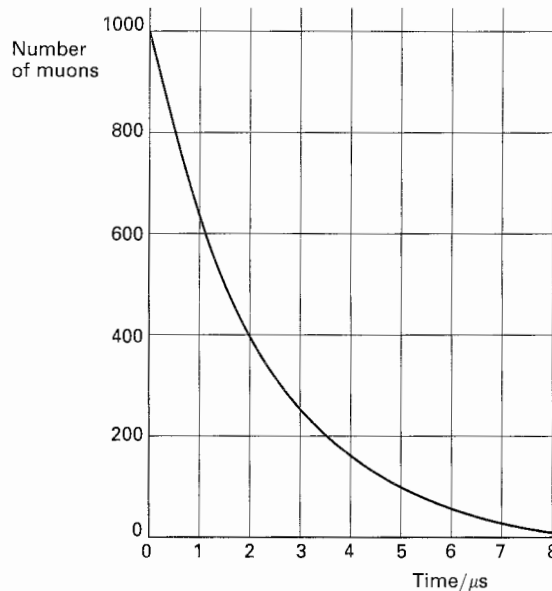
- In terms of the speed of light, c , what is the speed of the rocket relative to the Earth?
- How long does the journey take as measured by a clock on the Earth?

- The mean lifetime of muons at rest is $2.2 \mu\text{s}$. An observer notes that they travel an average of 2000 m before decaying. In terms of the speed of light, c , what is the speed of the muons relative to the observer?

- State the two postulates of Einstein's special theory of relativity.
- Muons are created in the upper atmosphere by cosmic rays. They are negatively charged particles with a mass two hundred times that of an electron and a charge of the same size and sign as an electron. They are very short-lived, decaying into an electron and two neutrinos. The graph illustrates the short-lived nature of stationary muons: it shows the number, N , of muons surviving against time, t .

For every 1000 muons detected at a height of 2000 m, 700 are detected at sea level.

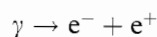
- Use the graph to estimate how long it would take for 1000 stationary muons to decay to 700.
- How far would a light photon moving through the atmosphere travel in this time.



- Muons produced by cosmic radiation travel at a speed of 99.8% of the speed of light. Use the theory of special relativity to explain why such a high percentage of the muons produced by cosmic radiation reach sea level. [J (specimen), '96]

- Calculate the percentage increase in mass when a particle is accelerated from rest to 1% of the speed of light.
- A metal cube has a density of $9.0 \times 10^3 \text{ kg m}^{-3}$ when at rest in a laboratory. If the cube is caused to move perpendicular to two of its faces at a speed of $2.4 \times 10^8 \text{ m s}^{-1}$ relative to an observer in the laboratory, what is its density as measured by this observer? (Speed of light = $3.0 \times 10^8 \text{ m s}^{-1}$.)
- A particle is travelling at 60% of the speed of light. What is the ratio of (a) its rest mass to its relativistic mass, (b) its kinetic energy calculated on the basis of Newtonian mechanics to that on the basis of relativistic mechanics?

- A high-energy gamma-ray photon can spontaneously create an electron and a positron:



Assuming that the rest mass of an electron and that of a positron are each 9.1×10^{-31} kg, that $c = 3.0 \times 10^8$ m s⁻¹ and that the Planck constant, h , is 6.6×10^{-34} J s, calculate the *maximum possible* wavelength of the photon.

- (b) According to special relativity theory the inertial mass, m , of an electron moving with speed v is given by

$$m = m_0 \left(1 - \frac{v^2}{c^2} \right)^{-1/2}$$

where m_0 is the rest mass of the electron and c is the speed of light *in vacuo*.

- (i) Use the equation to explain what happens to the mass m if the electron is accelerated to speeds very close to that of light.

How does the theory forbid electrons from travelling at speeds greater than c ?

- (ii) Describe one additional relativistic effect exhibited by high speed electrons. [L, '91]

11. By considering a photon in a box, derive the expression $E = mc^2$.
12. Can a particle with a rest mass m_0 have a momentum of m_0c , where c is the speed of light? Explain your answer.
13. An electron and a positron, each with negligible kinetic energy, annihilate each other and create two identical photons. Calculate (a) the energy released by the annihilation, (b) the frequency of the photons. (Mass of electron = mass of positron = 9.11×10^{-31} kg, speed of light = 3.00×10^8 m s⁻¹, Planck's constant = 6.63×10^{-34} J s.)

14. Explain how the principle of conservation of energy has had to be modified in the light of the theory of special relativity.
15. What percentage error is introduced when the kinetic energy of a particle moving at 10% of the speed of light is calculated on the basis of Newtonian mechanics rather than relativistic mechanics?
16. A particle of rest mass m_0 has a kinetic energy of $\frac{1}{2}m_0c^2$. What is the speed of the particle in terms of the speed of light, c ?
17. On the basis of 'force = rate of change of (relativistic) momentum', show that a particle of rest mass m_0 acted on by a force F acquires an acceleration dv/dt given by $F = m_0\gamma^3 dv/dt$ where $\gamma = (1 - v^2/c^2)^{-1/2}$.
18. An electron has a kinetic energy of 3.3×10^{-13} J. At what fraction of the speed of light is the electron moving? (Mass of electron = 9.1×10^{-31} kg, speed of light = 3.0×10^8 m s⁻¹.)
19. What is (a) the speed, (b) the momentum of an electron that has been accelerated from rest through a potential difference of 20 000 V? (Charge on electron = 1.6×10^{-19} C, mass of electron = 9.11×10^{-31} kg, speed of light = 3.00×10^8 m s⁻¹.)
20. The Stanford linear accelerator is 3.0 km long and accelerates electrons to an energy of 20 GeV. What is the length of the accelerator in the rest frame of the electrons? (Charge on electron = 1.6×10^{-19} C, mass of electron = 9.1×10^{-31} kg, speed of light = 3.0×10^8 m s⁻¹.)