

## Homework 5 - General Relativity

1. Einstein's theory of general relativity can be used to describe the motion of objects in non-inertial frames of reference. The equivalence principle is a key assumption of general relativity.

(a) Explain what is meant by the terms:

- (i) *non-inertial frames of reference*;
- (ii) *the equivalence principle*.

(b) Two astronauts are on board a spacecraft in deep space, far away from large masses. When the spacecraft is accelerating, one astronaut throws a ball towards the other, as shown in Figure 1.

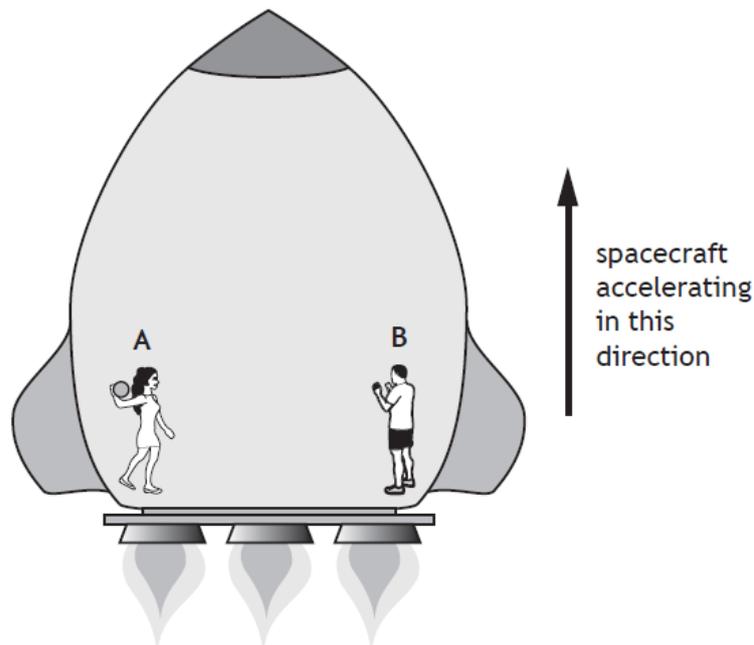


Figure 1

- (i) Sketch the path that the ball would follow in the astronaut's frame of reference.
- (ii) The experiment is repeated when the spacecraft is travelling at a constant speed. Sketch the path that the ball would follow in the astronaut's frame of reference.

(c) A clock is on the surface of Earth and an identical clock is on board a spacecraft which is accelerating in deep space at  $8.0 \text{ ms}^{-2}$ .

State which clock runs slower.

Justify your answer in terms of the equivalence principle.

2. Einstein's theory of special relativity is appropriate for inertial frames of reference and his theory of general relativity is appropriate for non-inertial frames of reference.

(a) State what is meant by an inertial frame of reference.

(b) An astronaut on a rocket ship suspends a 3.0 kg mass from a newton balance. The reading on the balance is 29.4 N. The astronaut concludes that the rocket ship is at rest on the Earth's surface. By referring to the equivalence principle, describe the other situation that would result in a reading of 29.4 N on the newton balance.

(c) The rocket ship travels away from Earth and scientists on Earth construct a world line for the rocket ship's motion, which is shown in Figure 2.

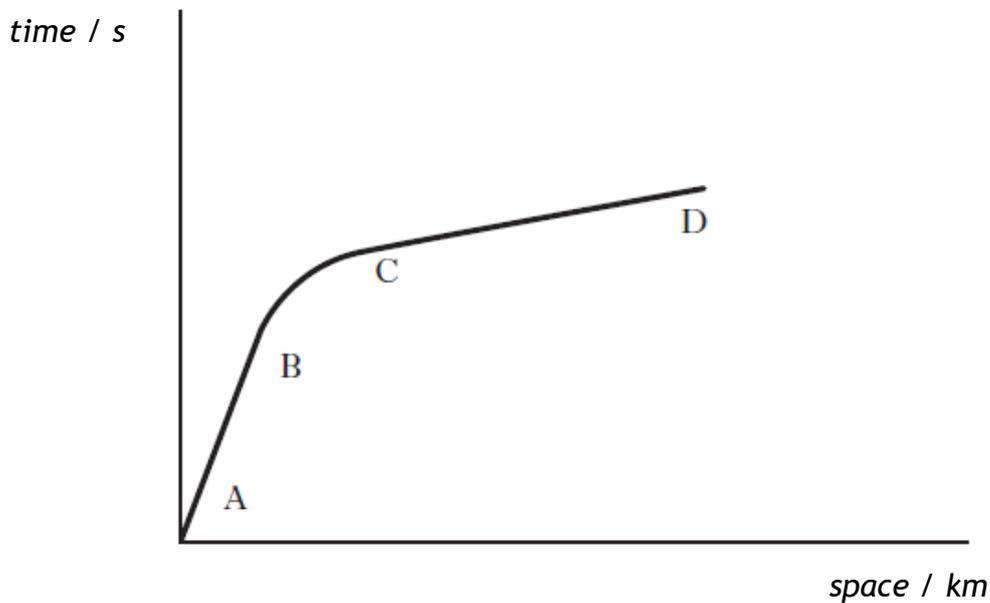


Figure 2

Describe the motion of the rocket ship between:

- (i) A and B;
- (ii) B and C;
- (iii) C and D.

3. The world lines for three objects A, B and C are shown in Figure 3A.

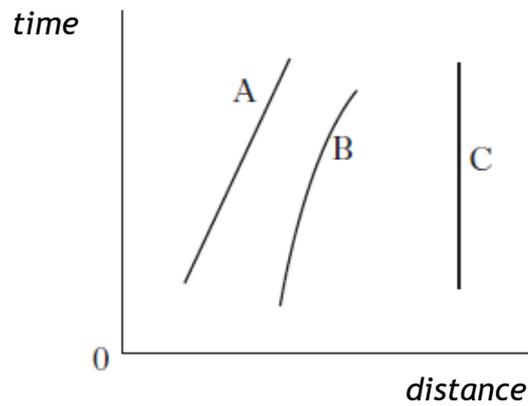


Figure 3A

- (a) State which of these objects Einstein's Theory of General Relativity applies to. Justify your answer.
- (b) A rocket ship is accelerating through space. Clocks P and Q are at opposite ends of the ship as shown in Figure 3B. An astronaut inside the rocket ship is beside clock P and can also observe clock Q.

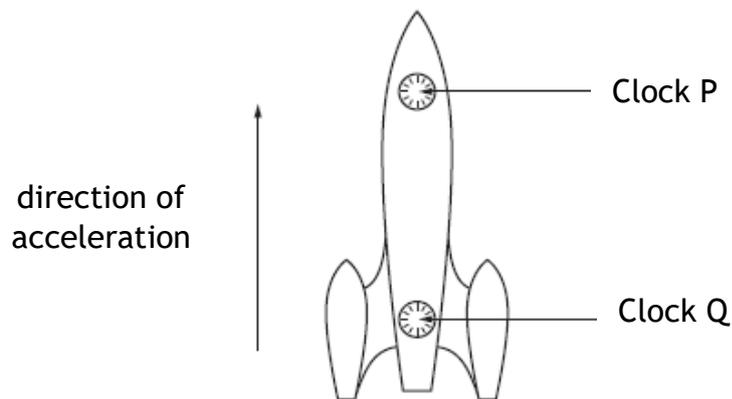


Figure 3B

State how the passage of time measured by clock P compares to the passage of time measured by clock Q.

You must justify your answer.

- (c) Part of an astronaut's training is to experience the feeling of "weightlessness". This can be achieved inside an aircraft that follows a path as shown in Figure 3C.



Figure 3C

Use the equivalence principle to explain how this "weightlessness" is achieved.

4. A commercial airline pilot talking to his friend, who is a member of the ground crew, states:

*“Of course, according to Einstein’s theories, flying at high speed at high altitude means that I’m going to age much slower than you will.”*

Using your knowledge of physics principles, comment on the pilot’s statement.