General Relativity

2013 Revised AH Physics

Marks

4. (*a*) The world lines for three objects A, B and C are shown in Figure 4A.

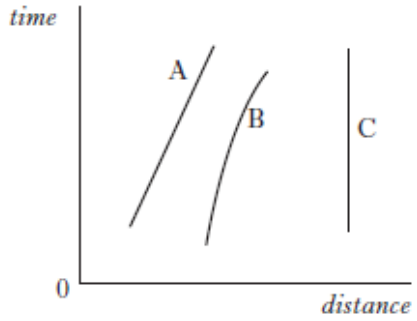


Figure 4A

To which of these objects does the General Theory of Relativity apply? Explain your choice. **2**

(*b*) A rocket ship is accelerating through space. Clocks P and Q are at opposite ends of the ship as shown in Figure 4B. An astronaut inside the rocket ship is beside clock P and can also observe clock Q.

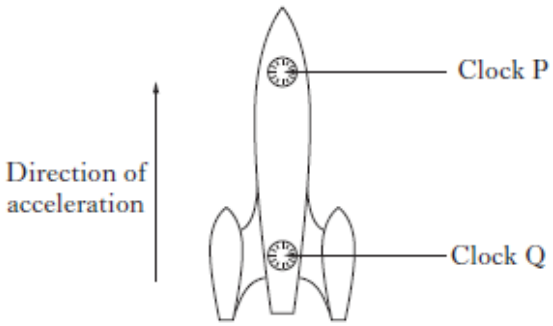


Figure 4B

What does the astronaut observe about the passage of time for these clocks? Justify you answer. **2**

(*c*) Part of an astronaut's training is to experience the effect of "weightlessness". This can be achieved inside an aircraft that follows a path as shown in Figure 4C.

Figure 4C

Use the equivalence principle to explain how this "weightlessness" is achieved. **2**

Marks

4. Cygnus X-1 is an X-ray source in the constellation Cygnus that astrophysicists believe contains a black hole. An artist's impression is shown in Figure 4A.

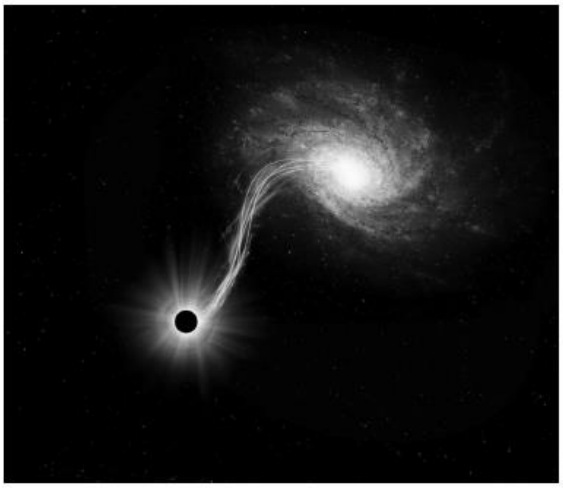


Figure 4A

The mass of the black hole has been determined to be 14·8 Solar masses.

(*a*) (i) State what is meant by the Schwarzschild radius of a black hole. **1**

(ii) Calculate the Schwarzschild radius of the black hole in Cygnus X-1. **3**

Marks

5. 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."*

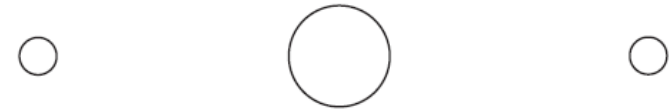
Using your knowledge of physics principles, comment on the pilot's statement. **(3)**

Marks

2. (*a*) With reference to General Relativity, explain why the Moon orbits the Earth. 2

(*b*) General Relativity also predicts gravitational lensing.

Figure 2 shows the relative positions of Earth, a massive object and a distant star.



Not to scale

Figure 2

Copy the diagram. On your diagram show:

(i) the path of light from the star to Earth; **1**

(ii) the observed position of the star from Earth. **1**

(*c*) Two students visit the tallest building on Earth. Student A takes a lift to the top of the building while student B waits at the bottom. General Relativity predicts that time will not pass at the same rate for both students. For which student does time pass at a slower rate?

You must justify your answer. **2**

(6)

THIS MARGIN

5. 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*; 1

(ii) *the equivalence principle*. 1

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

(i) On Figure 5A sketch the path that the ball would follow in the astronauts' frame of reference. 1

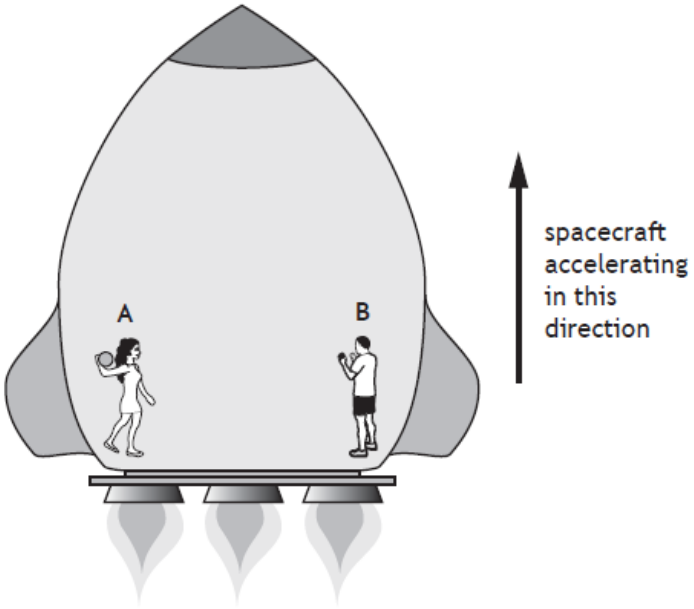


Figure 5A

WRITE IN THIS MARGIN

5. (b) (continued)

(ii) The experiment is repeated when the spacecraft is travelling at constant speed.

On Figure 5B sketch the path that the ball would follow in the astronauts' frame of reference. 1

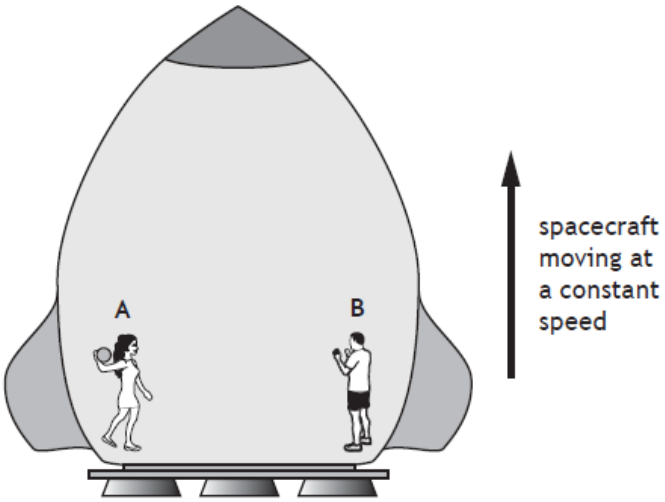


Figure 5B

(An additional diagram, if required, can be found on *Page 40*.)

(c) A clock is on the surface of the Earth and an identical clock is on board a spacecraft which is accelerating in deep space at 8 m s^{-2}.

State which clock runs slower.

Justify your answer in terms of the equivalence principle. 2

MARGIN

6. (a) The world lines for three objects A, B and C are shown in Figure 6A

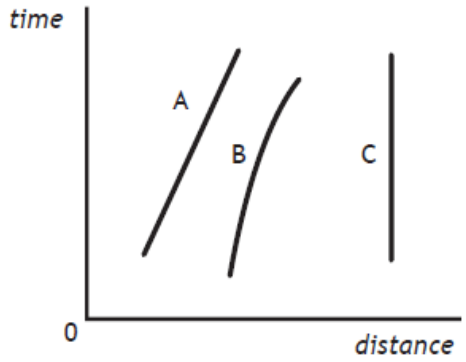


Figure 6A

To which of these objects does the General Theory of Relativity apply? Explain your choice. 2

(b) A rocket ship is accelerating through space. Clocks P and Q are at opposite ends of the ship as shown in Figure 6B. An astronaut inside the rocket ship is beside clock P and can also observe clock Q.

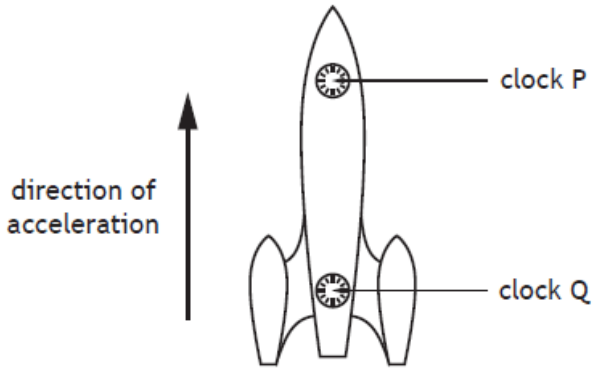


Figure 6B

What does the astronaut observe about the passage of time on these clocks?

Justify your answer. 2

6. (continued)

(c) Part of an astronaut's training is to experience the effect of "weightlessness". This can be achieved inside an aircraft that follows a path as shown in Figure 6C.

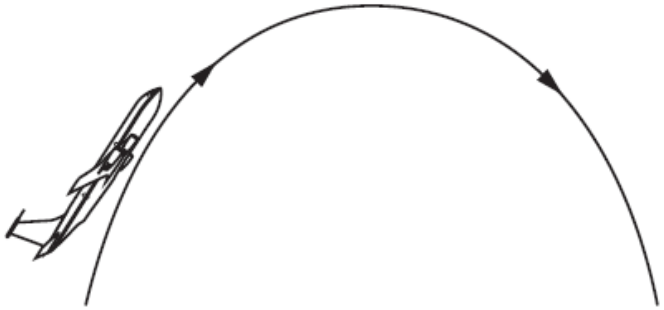


Figure 6C

Use the equivalence principle to explain how this "weightlessness" is achieved. 2