State Examination Commission – Physics Higher Level, 2008

Question 6

State Newton's law of universal gravitation. (6)
The international space station (ISS) moves in a circular orbit around the equator at a height of 400 km.
What type of force is required to keep the ISS in orbit?
What is the direction of this force? (6)
Calculate the acceleration due to gravity at a point 400 km above the surface of the earth.
An astronaut in the ISS appears weightless. Explain why. (14)
Derive the relationship between the period of the ISS, the radius of its orbit and the mass of the earth.
Calculate the period of an orbit of the ISS. (18)
After an orbit, the ISS will be above a different point on the earth's surface. Explain why.
How many times does an astronaut on the ISS see the sun rise in a 24 hour period? (14)
(gravitational constant = 6.6×10^{-11} N m^2 kg^{-2}; mass of the earth = 6.0×10^{24} kg; radius of the earth = 6.4×10^6 m)

State Newton's law of universal gravitation. (6)

Basic statement

What type of force is required to keep the ISS in orbit? What is the direction of this force? (6)

Centripetal force - directed towards the centre of the circular orbit.

Calculate the acceleration due to gravity at a point 400 km above the surface of the earth.

$mg = GMm/(r + h)^2$
$g = GM/(r + h)^2$
$= (6.6 \times 10^{-11})(6.0 \times 10^{24})/(6.4 \times 10^6 + 4 \times 10^5)^2$
$= 8.6\ ms^{-2}$

An astronaut in the ISS appears weightless. Explain why. (14)

Both the astronaut and the ISS are in a continual state of free fall towards the earth, at the same rate, so that the astonaut does not feel a sense of support and ***appears*** weightless. The astronaut exerts no force on the floor, and there is no normal reaction experienced by the astronaut.

Derive the relationship between the period of the ISS, the radius of its orbit and the mass of the earth.
Calculate the period of an orbit of the ISS. (Link) (18)

Radius of orbit of ISS, $d = r + h$, where r = radius of earth and h = height above surface of earth.

Centripetal force = Gravitational force
$mv^2/d = GMm/d^2$
So, $v^2 = GM/d$
Now the period, $T = 2\pi d/v$ (distance travelled in one orbit/speed)
So, $T^2 = 4\pi^2 d^2/v^2$
$T^2 = 4\pi^2 d^3/GM$
$T^2 = 4\pi^2(6.4 \times 10^6 + 4 \times 10^5)^3/(6.6 \times 10^{-11} \times 6.0 \times 10^{24}) = 3.13 \times 10^7\ s^2$
$T = 5.60 \times 10^3\ s = 93.3\ min$ (1½ hours)

After an orbit, the ISS will be above a different point on the earth's surface.

Because the earth itself is rotating about its own axis with a different period to that of the ISS.

How many times does an astronaut on the ISS see the sun rise in a 24 hour period? (Link) (14)

24/1.5 = 16 sunrises