a place of mind

FACULTY OF EDUCATION

Department of
Curriculum and Pedagogy

Physics

Astrophysics

Science and Mathematics
Education Research Group

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Astrophysics

Retrieved from http://www.theguardian.com/culture/tvandradioblog/2014/mar/17/week

Astrophysics

The following questions have been compiled from a collection of questions submitted on PeerWise (https://peerwise.cs.auckland.ac.nz/) by teacher candidates as part of the EDCP 357 physics methods courses at UBC.

Astrophysics I

SPACEMONAUTS! The Earth is in peril! Evil aliens have invaded and threatened to blow up the world! From the Spacemonaut headquarters in the International Space Station (ISS), our brave leader, Sir Chris Hadfield, has come up with a daring plan to soothe the aliens' rage and save the Earth by singing Rocket Man while rocking out on his SpaceGuitar.

Retrieved from: http://www.ctvnews.ca/canada/chris-hadfield-calls-prospect-of-soon-commanding-iss-surreal-1.1177283

Astrophysics I continued

Sir Chris only has two hands, though, and in order to successfully soothe the aliens, he needs to ensure that his microphone stays close to him. He holds up the microphone and lets it go so that it starts from a state of rest in relation to him and the ISS. The microphone is not connected to anything (see picture on previous page).

As Sir Chris sings his song from orbit, what will happen to his microphone? Choose the best answer.

A. The microphone will stay where it is because there is no gravity in space.
B. The microphone will slowly drift upwards because it is following a straight path as the ISS follows a curved orbit.
C. The microphone will stay in place because gravity acts equally on it, the ISS and Sir Chris.
D. The microphone will drift downwards because of the pull of gravity.

Solution

Answer: C

Justification: A common misconception about space is that there is no gravity. This is incorrect, especially with relation to objects (like the ISS, the mic and Sir Chris) orbiting large bodies (like the Earth) close to its surface (400km above the surface vs. 6371km radius of the Earth).

Gravity is therefore acting on the mic, the ISS and Sir Chris equally, and the mic will stay where it is (C).

In fact, the ISS is actually continuously falling towards the Earth, but due to its incredible horizontal velocity of around 27 600 km/h it curves around the Earth's surface, instead of falling down towards it. Without the effect of gravity, the ISS would float away into space.

See this video for a great explanation:
https://www.youtube.com/watch?v=iQOHRKKNNLQ

Astrophysics II

In order to have his broadcast of soothing music reach all the corners of the Earth, Sir Chris Hadfield (Daring Spacemonaut Leader!) decides to double the ISS's orbital distance from Earth from 400 km to 800 km.

If the ISS originally experienced gravitational acceleration g_1, what will the new gravitational acceleration acting on the ISS (g_2) be?

r_{Earth} = 6371km

A. $g_2 = 0.50g_1$
B. $g_2 = 0.90g_1$
C. $g_2 = 0.25g_1$
D. $g_2 = 0.95g_1$
E. $g_2 = 2.00g_1$

Solution

Answer: B

Justification:

Here you must be aware of the equation: $g = \frac{GM}{r^2}$

where g is the acceleration due to gravity, **G** is the gravitational constant, **M** is the mass of the Earth, and **r** is the distance from the center of the Earth. **G** and **M** stay constant, and **r** changes.

The original orbital radius is equal to the radius of the earth (6371 km) plus the distance of the ISS above the Earth (400 km). Hence the initial orbital radius is:

$$r_i = 6771\text{km}$$

Solution continued

The new orbital radius is the radius of the Earth (6371 km) plus the new orbital height (800 km). Hence the final orbital radius is:

$$r_f = 7171\text{km}$$

First, find the ratio of the squares of the two radii:

$$g_1 = \frac{GM}{{r_i}^2} \qquad g_2 = \frac{GM}{{r_f}^2}$$

$$g_1 {r_i}^2 = GM \qquad g_2 {r_f}^2 = GM$$

As the right sides of both equations are G*M, we can equate the two left sides to find:

$$g_1 {r_i}^2 = g_2 {r_f}^2$$

Solution continued 2

And so we get: $$g_2 = g_1 \frac{{r_i}^2}{{r_f}^2}$$

Inserting r_i = 6771km and r_f = 7171km, we find $g_2 = 0.90 g_1$

Therefore **B** is correct!

If you forgot to account for the radius of the Earth in the calculations (using 400 and 800km instead of 6771 and 7171km), and forgot to square the radii, you will get answer **A**.

If you forgot to account for the radius of the Earth, but remembered to square the radii, you will get answer **C**.

If you forgot that the radii are squared, you will get answer **D**.

If you forgot to account for Earth's radius, forgot to square the radii, and inverted the ratio of the radii, you will get answer **E**.

Astrophysics III

Good News! With your help, Sir Chris has successfully soothed the invading aliens! They have requested to meet with you all for a smooth jazz jam session aboard the ISS!

To meet with the aliens, you return the ISS to its original position, orbiting 400km above the Earth.

What is the acceleration due to gravity, in m/s^2, acting on you?

A. 3.62×10^{6}
B. 9.81
C. 9.81×10^{6}
D. 8.69
E. 8.69×10^{6}

Given: $G = 6.67\times10^{-11}\ m^3/kg\times s^2$

$M_{Earth} = 5.97\times10^{24}$ kg

$m_{ISS} = 417\ 289$ kg

$r_{Earth} = 6371$ km

Solution

Answer: D

Justification: To calculate the acceleration due to gravity we use the formulas:

$$F_g = \frac{GMm}{r^2} \quad \text{and} \quad F_g = ma$$

F_g = Force due to gravity

G = Gravitational constant

M = Mass of the Earth

m = Mass of the ISS

r = Distance between the ISS and the center of the Earth (6371+400km)

a = Acceleration due to gravity

Solution continued

Since $F_g = F_g$, then: $\frac{GMm}{r^2} = ma$

m cancels from both sides of the equation and we get:

$$a = \frac{GM}{r^2}$$

If we put in the given values for G, M and r, we get a = 8.69 m/s^2.

Note: Don't forget to convert the radius, r, from km into m!

This makes **D** the correct answer.

It is interesting to note that we did not need the mass of the ISS to get the answer. It was Galileo who found that the acceleration due to gravity depends only on the mass of the gravitating object (the Earth in this case) and the distance from it. It does not depend on the mass of the object being pulled.

Solution continued 2

If you solved the first equation for F_g you will get 3.62×10^6 N, answer **A**. This represents the *force*, not the *acceleration* of the ISS.

If you forget to add the distance of the ISS (400 km) to the radius of the Earth, you will get 9.81 m/s^2, the acceleration due to gravity at the surface of the Earth (answer **B**)

If you forgot to convert the orbital radius (6771 km) into meters, you will get answer **E**.

This answer can also be answered **conceptually** – since we know that the acceleration due to gravity very close to the Earth's surface (g) is approximately 9.81 m/s^2, then we know that the answer must be a little bit smaller (since the ISS is further away from the Earth). The only answer that satisfies these conditions is **D**. The answer of 8.69 m/s^2 might be surprising, since it is not much smaller than 9.81 m/s^2, and yet the ISS is 400 km above the Earth's surface. But we must remember that the radius of the Earth is much larger, at 6371 km.

Astrophysics IV

The strongest person on the moon and the strongest person on the Earth decide it is time to determine who is the strongest. However, NASA's reduced budget has resulted in the cancelation of the space shuttle program leaving the two competitors no method of getting to the same location.

Instead of competing in the same place, they decide to try and create a contest that accounts for the differences in gravitational field strength. In the end they decide on the following format of contest:

The winner of the contest is the person who accelerates the block to the highest speed by the end of the track.

Astrophysics IV continued

They decide that the block on Earth should be one ton and the block on the moon should be 6.06 tons.

The acceleration due to gravity on the moon is 1.62 m/s^2 while on Earth it is 9.82m/s^2.

The tracks are the same length and frictionless.

Decide if the contest is fair and justify your answer.

Note:

1 ton = 1000kg

A. The contest is fair because the gravitational field has no impact on the outcome of the contest.

B. The contest is fair because the mass of the Moon's block is greater than that of the Earth's block.

C. The contest is not fair because the gravitational field of the Earth is greater than that of the Moon.

D. The contest is not fair because the Moon's block has a greater mass than that of the Earth's block.

Solution

Answer: D

Justification:

When pulling a block along a frictionless surface, the weight of the object doesn’t affect how hard it is to accelerate the object. This is because the force of gravity is acting directly down towards the center of the Earth (or moon), which doesn’t act against any of the horizontal force the contestants apply to the blocks. The only thing resisting the acceleration of the contestants is the mass of the blocks. Even though the block on the Moon weighs the same as the block on the Earth, the masses are different and therefore the contest is not fair.

Astrophysics V

An observatory detects a new galaxy, and notices that its hydrogen emission spectrum is shifted from what would normally be expected. A specific band that normally has a wavelength of 410.2 nm is instead noted to have a wavelength of 502.9 nm. Using this information, how far away is the galaxy?

Assume that the rate of expansion of the universe is constant, and the Hubble constant is 67.8 (km/s)/Mpc.

A. 1000 Mpc
B. 10,000 Gpc
C. 2000 Mpc
D. 1000 ly
E. 1 billion ly

Solution

Answer: A

Justification: To find the distance of a galaxy, we need to use the redshift to determine how fast it is moving away from us. Because the universe is expanding at a constant rate as we have assumed, this speed is directly related to how far away from us the galaxy is.

First, we can find the redshift by dividing the difference in the observed wavelengths of light by the wavelength that was emitted. Because we know the wavelength of the hydrogen emission spectrum, we can determine the difference between the emitted and the observed wavelengths.

$z = \Delta\lambda / \lambda_{emitted}$

$z = (502.9 \text{ nm} – 410.2\text{nm}) / 410.2 \text{ nm}$

$z = 92.7 \text{ nm} / 410.2 \text{ nm}$

$z = 0.23$

Solution continued

We can determine from this relatively small redshift that we can directly equate the redshift velocity with the recessional velocity. Because the redshift is caused not only by relativistic velocities, but also by the expansion of the universe, if the redshift was much larger, the relationship between the galaxy's redshift velocity and its recessional velocity would not be as simple. But because the redshift is small, we do not need to worry about this and assume that $v_{rs} = v_r$.

We know that the redshift is directly related to the galaxy's velocity, in the form of:

$z = v/c$ (c = speed of light in a vacuum = 300 000 km/s)

Thus, rearranging the equation we can express:

$v = zc$

Solution continued 2

We can use this velocity in Hubble's Law to determine the distance to the galaxy.

$v = H_0 \times D$

$zc = H_0 \times D$

$D = zc \,/\, H_0$

$D = (0.23 \times 300{,}000 \text{ km/s}) / 67.8 \text{ (km/s)/Mpc}$

$D = 1000$ Mpc (Answer **A**)

A quick approximate calculation if you couldn't use a calculator:

$z = (500 – 400)/400 = 100/400 = 1/4 = 0.25$

$D = (0.25 \times 30{\times}10^4) \,/\, 70 = (7.5{\times}10^4) \,/\, 70 \approx 1{\times}10^3 = 1000$ Mpc

Solution continued 3

B is not correct. You might have gotten this answer if you forgot that Hubble's Constant used km/s to describe c and instead used m/s. This distance is in fact outside the observable universe, so if you got this answer, that should be a very obvious warning.

You might have gotten **D** if you forgot to include units in your calculations, and used light years instead of Mpc as the units. This number is in fact far too small if we are using light years, as one Mpc (megaparsec) is approximately 3 000 000 light years.

E is about the right scale in terms of number of light years, but it is still not accurate enough. The distance is actually about 3 billion light years.