What's the Matter? Part V

Last week we compared the **weights** and **masses** of objects on different celestial bodies. We learned that **weights** differ, depending upon the celestial body, but **mass** does not change. Then we posed this question:

> *I have seen video of astronauts on the moon. If their masses did not change, how come they were able to jump so high?*

[1] Buzz Aldrin, Apollo 11, 7/20/69

We asked you to think about the forces on the astronaut as his motion changes from at rest (standing on the moon's surface) to moving upward.

So what's the answer? Why does it appear to be so much easier for an astronaut to jump on the moon? Think about your body's motion as you jump.

- First, jump, paying close attention to what you do with your knees and arms.
- Now stand and imagine your body locked in position. You can not bend your feet, ankles, or knees. Your arms are taped to your body in a straight-down position. Now, try to jump.

To set yourself in upward motion you need to get the floor to push you up. You do this by throwing your arms up and by straightening your bent knees.

You are skeptical! OK, stand on your bathroom scale and throw your arms upward. Notice that the scale shows a short but definite increase upward. When you throw your arms upward, your body exerts an increased downward force on the scale and the scale, in turn, pushes up on your body for just an instant with a force greater than your weight. The scale records the short but significant change in weight.

Now stand on your bathroom scale and watch what happens when you straighten your bent knees. It's the same story. Straightening your knees increases the force your body exerts on the scale and the scale increases the force it exerts on your body.

When you straighten your bent knees and throw your arms upward, you are getting the floor to increase its upward force on your body.

What forces are in action?

When the astronaut is standing on the moon's surface, the following forces are involved:

- There is an upward push of the moon's surface on the astronaut and a downward force of the astronaut on the moon's surface. (Remember, forces act in pairs. For instance, if you have a coffee cup sitting on a table, the cup is *pushing down* on the table. The table is also *pushing up* on the cup.)
- There is an attractive force between the moon and the astronaut.

When the net force exerted by all these forces is zero, the astronaut does not move. This means that all the pushes and pulls, in effect, cancel each other out. No motion occurs.

What happens when the astronaut jumps?

At the instant the astronaut initiates his jump (flexes and straightens his legs and throws his arms upward to increase the force he is exerting on the moon's surface) the forces ***on*** the astronaut are:

- The downward force of attraction exerted by the moon
- The upward push of the moon

The *upward push* is greater than the astronaut's **weight** (the downward force on the astronaut), so his motion is upward. The *upward push* from the moon is greater because the astronaut just exerted an increased *downward push* by flexing and straightening his legs and throwing his arms upward. This causes the previously balanced scale (astronaut stationary) to tip:

- The moon's surface is exerting a greater *force* (push up) than the attractive *force* of the moon (pull down), so the astronaut is set into motion in an upward direction.

Why is the jump higher than on Earth?

Because the astronaut can flex his knees and throw his arms upward and exert the same force on the moon as on the Earth but **weighs** less on the moon, he can jump higher on the moon. Remember, last week we introduced this definition:

Weight: the force of attraction between an object and the celestial body it is on

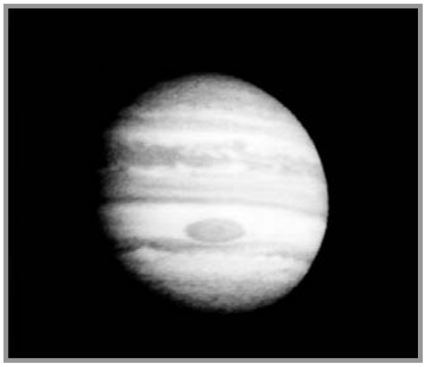
We know that the force of attraction of the moon is 1/6 that of Earth. If the astronaut exerts the same downward push on the moon as he does on Earth, the moon's surface will be pushing back with the same force as Earth's surface does. However, the force of attraction of the moon on the astronaut is less than that of the Earth, so the change in the astronaut's motion is greater on the moon than on the Earth .

In fact, in actual moon landings, the astronauts were instructed to exert less force when they jumped on the moon. Pushing down on the moon's surface with too much force would have caused the astronauts to jump too high, endangering them.

What about "jumping on Jupiter?"

Suppose an astronaut could travel to Jupiter. How high do you think the astronaut could jump on Jupiter if she exerts the same force as she did when jumping on Earth?

Last week we discussed that the force of attraction between Jupiter and an object on its surface was greater than the force of attraction between the Earth and an object on its surface. The object **weighs** more on Jupiter than on Earth. Therefore, the astronaut will not be able to jump as high on Jupiter if she exerts the same force as on Earth. The explanation has the same logic as the moon explanation:



[2] Jupiter 1/1/75

We know that the force of attraction between the astronaut and Jupiter is 2.529 times that of Earth. If the astronaut exerts the same downward push on Jupiter as she does on Earth, Jupiter's surface will be pushing back with the same force as Earth's surface does. However, the downward force of Jupiter *on the astronaut* is greater than the Earth, so the astronaut cannot jump as high.

With knowledge of the attractive force between celestial bodies and objects on their surface* (**weight**), you and your students can predict and compare how high astronauts can jump in various parts of the universe.

You might want to check out these websites for more information on comparing weights among different celestial bodies.

- http://mac.usgs.gov/visitors/html/quiz/moon.html
- http://btc.montana.edu/ceres/html/weight.html

[1] http://grin.hq.nasa.gov/IMAGES/SMALL/GPN-2001-000013.jpg
[2] http://grin.hq.nasa.gov/IMAGES/SMALL/GPN-2000-001698.jpg