Weight and mass for young physicists

Chris Hall, ANSTO Australian Synchrotron – christoh@ansto.gov.au
Clara Teniswood - clara.teniswood@gmail.com

A reader response to the previous Young Physicists' article about buoyancy raised an interesting question regarding the difference between weight and mass. Would the Ever Given sit higher or lower in the water of the canal if it was nearer the south pole?

In other words, is the draft of a ship dependent on where in the world it is sailing? The answer to this question brings us back to considering the difference between mass and weight. We addressed this briefly in the buoyancy discussion. Just as an aside, as young physicists it's important you should nurture your skills of explanation. Learn how to tell someone about science who is not a physicist – perhaps a younger sibling. If you can successfully explain the weird things we learn and already know about physics, then you can say you truly understand them. One of my favourite sayings are along these lines attributed to Albert Einstein: 'The explanation you give as a scientist should be as simple as possible, but no simpler' [1].

How would you explain the difference we physicists understand between mass and weight? In everyday life those words are often used interchangeably, but as we saw in the last article when calculating the draft of the ship Evergreen, they are not the same. The two quantities are certainly proportional, but mass is a fundamental unit. It cannot be split into other units. Weight on the one hand is actually a force, measured in Newtons (the S.I. unit for force) [2]. One Newton is the force required to accelerate a one kilogram mass to a velocity of one meter per second, over the interval of a second. On the other hand, mass is a measure of the amount of material in an object. We can say it's the number of atoms that make up whatever it is we are measuring.

When we talk about a weight being in kilograms then, it should really be described as kilograms force (kg-f), and we need to agree on the gravitational pull to use it as a standard. If we know the local value of the gravitational acceleration, which in physics is usually given the letter 'g', we can then work out the mass. There is an internationally agreed value of g, which is 9.80665 m/s^2. That doesn't mean it's the same all over the world, though. The variation with latitude is about 0.5% for high latitude places, compared to the equator. For instance, in Sydney the value of g is 9.797 m/s^2. If you live in Melbourne, it is 9.800 m/s^2, and in London, England, it is 9.816 m/s^2.

On Mars, g is only 3.721 m/s^2. If you stood on Mars, you would weigh less than you do on Earth, because gravity is less. However, you would still have the same mass because you are made up of the same amount (and type) of 'stuff' (atoms). Next time you go in an elevator, take some scales with you and stand on them while you go up and down a few floors – what do you notice?

When we are explaining something, it is often useful to offer an illustration. Consider a sphere of pure silicon. Silicon is an abundant and remarkably useful element. I choose a ball of silicon as an example, because this is exactly what is used as our international standard mass. The Australian CSIRO have made a sphere of silicon for the international Avogadro project [3]. This shiny ball will be used as the new international kilogram reference object. It is exactly 1 kilogram, down to a precision of 10 parts per billion.

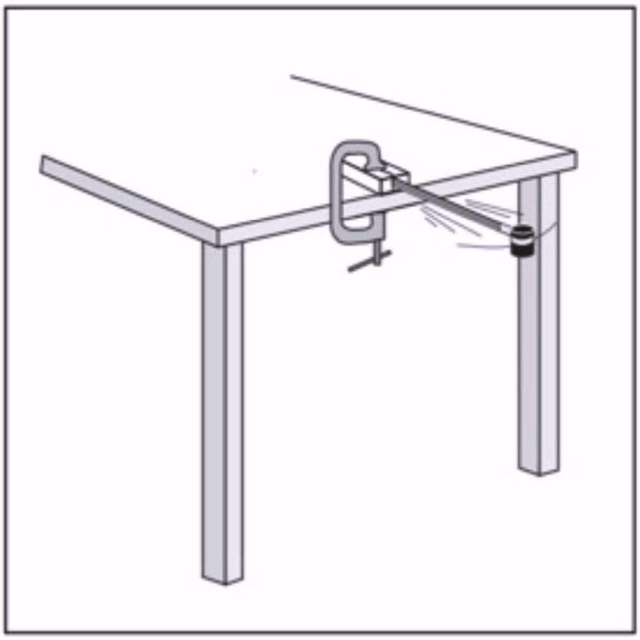
One kilogram silicon sphere. Source: [3].

At normal temperatures and pressures, silicon atoms like to stick to each other. So, silicon is said to be a solid material. It's also a crystalline solid since the atoms stick to each other in a nice regular pattern. It is easy to distinguish silicon atoms from any atoms in the air around it. The gas atoms in the air don't stick to each other, or stick to the silicon. They do regularly bump into the silicon atoms, but they won't stay. Because of this, we may define a precise number of atoms in our ball of silicon, and therefore its mass.

The question then is: how do we measure that mass? We could use a balance or some scales perhaps, but what if we were trying to make the measurement in a different gravity field, for instance on the Moon where $g_{Moon} = 1.62$ m/s^2 ? The answer lies in another physical phenomenon that is dependent on mass: inertia. Inertia only depends on the mass and how fast the mass is moving. Inertia does not depend on gravitational pull. For example, on the International Space Station (ISS) the astronauts float around weightlessly (we leave it to you to figure out why they are weightless; it's not because the ISS cruises a few hundred kilometres above the Earth's surface). Even though astronauts are weightless on the ISS, they still have mass. They still need to push themselves off one end to float to the other, so they still need to overcome their own inertia to move. On the ISS, with weight out of the equation, one could devise measurements to measure mass. Down on Earth, measuring mass and weight gets more entangled, but there are ways to use inertia to measure mass.

Have you learnt about the physics of guitar strings? One thing that you may know is that the string will change its tune (frequency) depending on its length, how tightly it is pulled (tension) and, most importantly, its mass. If we assume the string is made from the same material all along its length, then we can define a property called linear mass density, which can substitute for mass. If we fix the string's length and tension, then more massive strings sound lower than thinner ones. So, here is a way of measuring mass. A mass-measuring device that uses this technique is called an Inertial Balance. We can place our unknown mass into a system that oscillates (that is, to move back and forth from a central point) and measure the change in frequency of the oscillation. If accurately calibrated, this will give us the mass (rather than the weight). NASA has actually created instructions for how you can do this experiment at home or at school [4].

So now you should know the difference between mass and weight and that gravity varies depending on where you are. Thinking back to what you learnt about buoyancy in our previous article, can you now answer the question: would the Ever Given sit higher or lower in the water of the canal if it was nearer the south pole? Send your answers to aip_editor@aip.org.au; the first correct answers will win a (modest) prize.



Inertial Balance experiment. Source: [4].

References

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