How to embarrass your science teacher

Most science teachers are unaware that they don't really understand the ocean tides. They can hardly be blamed, because many school books are wrong about the tides.

But, this subject can be an interesting one to have a good discussion about. You can have the upper hand on your teacher when you understand the ocean tides before he/she does. If that's the case, you will also soon find out if you have a good teacher, or one of the other kind. This document provides you with a suggested outline for such a discussion.

The best place to start is to first check whether your teacher adheres to the wrong explanation or not. This question serves as a indicator:

Question 1: How can the pull of the moon make the water go up if that force is so small that we can't even notice it?

You will know that your teacher is on the right track when he/she answers something like:

Correct answer 1: The water isn't being 'pulled upward'. It's actually being pushed upward because the innumerable tiny attractive forces add up throughout the oceans into enough pressure to start heaping up water.

But, more likely, you will get one of the wrong – unfortunately very predictable – answers:

Incorrect answer 1.a.: Yes, the force is very small, but the oceans contain a lot of water, so that adds up.

At first glance this may seem like a correct answer, but it probably isn't. The red flag starts going up when teachers mention 'a lot of water' or 'the ocean is very large'. This typically indicates that they unwittingly believe, in this case, that a large mass reacts differently to a gravitational field than a small one. This is not the case. They will probably immediately acknowledge that, if you put it like that, but let's have some fun first.

Embarrassing reply 1: But the deserts are really large too; they contain a lot of sand. Why don't they go up as well? I don't believe there are tidal sand dunes sliding through the desert twice a day.

Now you will have confronted your teacher with the first misconception. The size of the oceans is relevant, but not because it means that they contain a large water mass. The size is relevant because it provides large distances for water pressure to accumulate. A fluid medium, with low internal friction – like water - can do this. Sand doesn't do that, not even if the mass of the sand is just as great as the mass of water.

Incorrect answer 1.b.: The difference in the moon's attraction pulls the earth into an elongated shape, a bit like a rugby ball, but not nearly so obvious. The ocean water conforms to that shape.

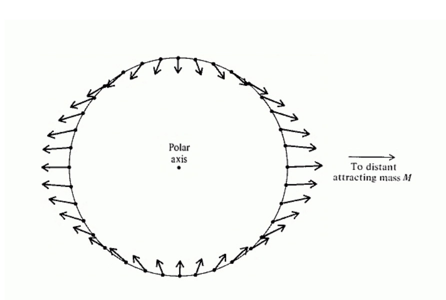
There is so much wrong with this answer that it's difficult to start. It does contain some truth, but it is incorrectly applied to provide a wrong answer. Indeed, the moon's gravitational attraction does produce 'tidal forces' which attempt to deform the earth into a rugby ball shape. But that deformation of the earth, underneath your feet, is known as 'earth tides'. They do happen, but they have nothing to do with the ocean tides.

It's the provided conclusion that ocean waters will automatically conform to that shape which is difficult to tackle, as no plausible mechanism is provided to support it. You could – correctly – go back to pointing out that this should also mean that desert sands conform to that shape as well. But this will probably be brushed off by an 'easy brush' like 'the desert sands cannot react as quickly as water', which is correct, but not relevant in this case. You'd better apply a new angle:

Embarrassing reply 1.b.: But that would also mean that great volumes of lava would start flowing out of volcanoes to cover the earth with great, rugby ball shaped, lava bulges.

The counter that water reacts faster won't help much, because – even so – you should then at least see the lava levels inside volcanoes start to rise noticeably during the high tide period. You won't.

[Intermezzo 1 The stretched earth and its magma]



Incorrect answer 1.c.: The tidal force envelope is shaped like this (teacher presents a picture, similar to the one shown on the left) . This represents the tidal forces on the surface water. They will pull the water up, underneath the moon and push it down at positions away from the moon.

This is a tricky one, because it's really just another variant of Incorrect Answer 1.b.. But it's tricky because it aims to make you accept that the water will simply assume the shape of the tidal force envelope. This actually ignores your original question, because it does not address the essential point that the forces shown in this tidal force envelope are incredibly small. The greatest force arrow here – the one 'pulling' towards the moon – is approximately $1/10,000,000^{th}$ the size of the force of gravity, which is pulling down.

But this is also at the root of the widespread, persistent fallacy that 'the moon pulls the water upward'. Many people, including a number of famous astrophysicists, believe and proclaim this. It shows that they stopped analyzing the tides at this exact stage. Had they tried to quantify these tidal forces, they would soon have seen that tidal forces are not capable of lifting anything. The only possible conclusion is that a very different mechanism must be at work, raising the ocean water.

So that's the best way to tackle this one; expose the impossibility of 'lifting' a mass, like the ocean, by tidal forces.

Embarrassing reply 1.c.: So, that means that, if you'd freeze the oceans solid, the ice crust would be lifted upward by a few feet.

Your teacher will probably sense that this cannot be the case (and of course it isn't). But, we're aiming to expose the 'pulling upward'-fallacy, so it's best to press the issue.

The danger is that he/she will try to confuse the issue by vague speculations about 'a fluid medium behaving very differently' and bulging up anyway. But you shouldn't let him/her get away with this, if it happens. In that case, press the issue with this reply:

Embarrassing reply 3b: But, if the total mass of the ocean is lifted by a few feet, by the tidal force, then why should it matter whether it's liquid or solid? Shouldn't they lift by the same amount, regardless of their state?

This should leave him/her struggling. Hopefully, if you have a good teacher, this will set him thinking on the right track. The not-quite-so-good teachers will keep on grasping at straws to always return to their original standpoint.

The aim of our reasoning is to nudge the discussion in the right direction. Eventually, when analyzing the ocean tides, you have to face the fact that the actual movement of water, at any location, in any direction, upward or sideways, is performed by pressure gradients in the water. This is how the tidal forces must be analyzed and applied to any model of the earth's oceans. Believe me when I say; when you do the mathematics – which is a tall order for most students and many teachers – the figures match what we see in the real world. A similar claim cannot be made by any model trying to employ a 'vertical pull'.

Anyway, you may not feel like having the discussion going in that direction. Then there is another approach which also yields considerable embarrassment and confusion:

Question 2: So, you say that the moon and the sun cause the water to be 'pulled upward' into great water bulges?

Your teacher will probably answer 'yes'. He/she should, if he/she actually believes in the fallacy. This sets him/her up for a barrage of confronting questions which can't be answered consistently with the accepted physical principles he/she is supposed to teach.

Question 2.b.: But, the moon is often over the southern hemisphere. If it is pulling the water towards it, into a bulge, then how can anyone in the northern hemisphere – for example at a latitude of 40 degrees North, like New York City – still see high tides? Shouldn't the water be pulled into a high bulge only in the southern hemisphere, when the moon is on their meridian?

Incorrect answer 2.b.a.: No, there is a second – antipodal – bulge which is then in the northern hemisphere and will still cause high water at northern latitudes.

Embarrassing reply 2.b.a: But that would mean that they'd only have one high tide per day.

Incorrect answer 2.b.b.: No, the larger low tide will make the average water level appear as 'high water' in comparison.

Hopefully your teacher is smarter than this, but I have heard this reply, more than once. I can only attribute it to 'grasping at straws'.

Embarrassing reply 2.b.a: That doesn't make sense, because it would mean that they'd have one very low tide, when the water pulls into the southern bulge, in between two higher tides, which are actually the average water level and then one very high tide, which is the antipodal water bulge.

Question 2.c.: So, if the water pulls up into a great bulge, then why do isolated island groups, like Hawaii typically have very modest tides? Shouldn't they be the highest tides of all because the pull of the moon is almost undisturbed in the middle of the ocean?

The great tidal handicap

Most teachers are handicapped by the fact that many school science books which discuss the ocean tides, discuss them at a very abstract level and typically don't follow through on how this applies to the real world. Many schoolbooks actually present half-baked or even wrong conclusions.

The aspect which most school books focus on is the fact that any mass which is closer to the moon will experience a greater gravitational attraction. Some books already stop the analysis right there and seem to think that this is 'explanation enough' for rising water on the surface closest to the moon.

From there, school books typically go straight to explaining spring- and neap tides. The actual mechanism responsible for creating tidal rises is typically completely ignored. So, it isn't surprising that many teachers are unaware that their knowledge about tide formation is incomplete. Most teachers will therefore assume that the tidal bulges, as shown in their text books, exist in the real world. As it takes a good deal of investigating to find out that this isn't true, most will never find out. Besides, the book says so and everybody seems to agree. So, why wouldn't it be true?

But what school books should do is point out that simply stating that 'there is a greater pull on the surface closest to the moon' isn't an explanation for water rising there. Only when students are aware of this they will start looking for the mechanism which does raise the high tides on Earth.

Only when you understand that the tidal rise is caused by horizontal components of the tidal forces accumulating into pressures can you begin to see what it takes to raise water. The next step is to see how this applies to a rotating earth. When you understand the mechanism, you can see how this can only raise water effectively at latitudes where the tidal forces can build up in an undisturbed band of water. The only band on Earth where this can happen is in the Southern Hemisphere, south of the continents, north of Antarctica. This is the only place where the tidal forces manage to raise water bulges which travel from east to west around the planet. They look nothing like the bulges which you would expect to see if you go by the simplistic explanation of most school books.

What we see, arriving at the beaches in the rest of the world is a secondary effect. The water raised in said southern band causes other water to start moving, as any raised water does, no matter what caused it to rise. The southern tidal rises cause energy to move through the world's connected oceans in the form of very large, but low amplitude waves. Such waves arrive at beaches around the globe, sometimes days after having been raised in the southern oceans. It's their interactions with oceans floors, land masses, currents, weather systems and local characteristics which determine when and how they arrive at your local beach. But the moon above your head has as good as no direct influence on that arrival. Its tidal forces were powerful enough to raise water in the southern band, but are too weak to have a noticeable influence when passing overhead.

The fact that the timing of the arrival of these 'secondary waves' approximately matches the expected timetable for the theoretical bulges seems to make many people believe that they are actually looking at 'one of those famous bulges arriving at their beach'. I find that very few people have ever checked to see whether the moon is overhead or not.

Anyway, handicapped by this mistaken notion, which is supported by the school books, most teachers believe that the tidal bulges exist, like the books suggest. They will therefore struggle to answer questions which require further insight.

When you are aware that local tides in the northern hemisphere have nothing to do with whether the moon is overhead or not, you can ask a lot of puzzling questions and let your teacher struggle to explain. At least, if your teacher is still convinced that local high tides are always ‘the arrival of a tidal bulge with the moon above it’.

Question 3: If the moon travels from east to west, dragging a tidal bulge underneath, then why does the high tide travel from north to south along the U.S. East Coast?

Correct answer 3: The tides arriving at the East Coast originate in the oceans of the southern hemisphere, south of the continents. The water rise there does travel from east to west (mind you; this is a wave travelling through the water, it isn’t the water itself moving.). After this tidal rise passes South Africa, a portion of its energy transfers to the waters of the Southern Atlantic Ocean and transfers north in the form of a wave with an enormous surface area but a very low amplitude. It passes into the North Atlantic Ocean, where it travels past Western Europe in northerly direction. Then it turns in westerly direction, passes south of Greenland and starts causing high tides along the U.S. East Coast, from Newfoundland to Florida, in a south-westerly direction.

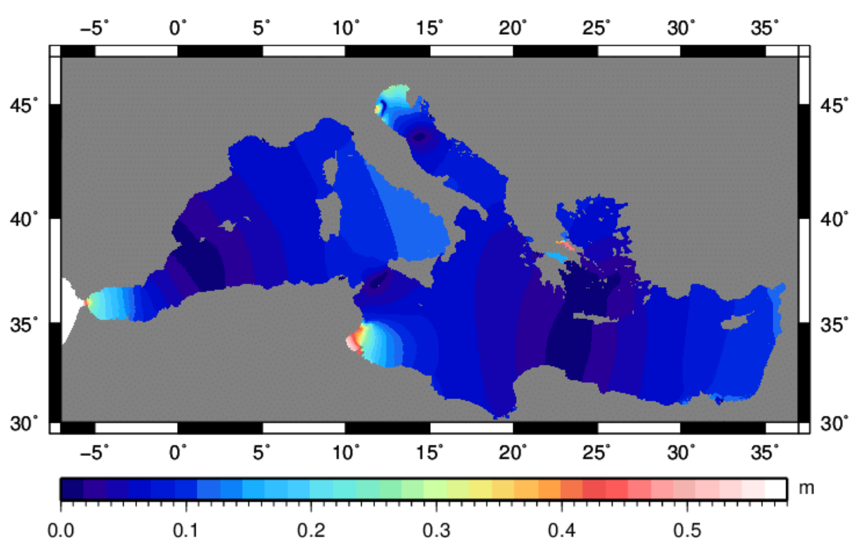
Question 4: If the moon travels from east to west, then how can you have high tides along the U.S. West Coast? Does the bulge travel over land?

Correct answer 4: The tides arriving at the West Coast originate in the oceans of the southern hemisphere, south of the continents as well. They are the result of energy breaking away from the tidal rise in the Southern Pacific Ocean. This energy makes its way north to arrive at the West Coast and cause high tides. No tidal bulge needs to travel over land.

Question 5: Why does the Mediterranean have almost no tides?

Incorrect answer 5: The Mediterranean doesn’t have high tides because it doesn’t contain enough water.

Strictly speaking, there is some truth in that answer, but usually the person giving such an answer has the wrong idea. This answer usually stems from the simplistic mistaken notion that you would need to have a large mass of water before it gets ‘pulled upward’ noticeably. Besides, when you look at the tidal amplitudes in the Mediterranean, it isn’t even true that there are only small tidal amplitudes in the Mediterranean. In this figure of tidal amplitudes caused by the moon it is visible that a few areas do show greater tidal amplitudes (depicted by colours towards red and beyond).



Tidal forces on water in the Mediterranean behave exactly the same as tidal forces on any other mass on Earth. Tidal movements occur when horizontal tidal force components accumulate into a water pressure gradient which is strong enough to initiate or support water movement. Even though the Mediterranean has shorter stretches and less water to accumulate such tidal force components, it does happen in a few areas, where the recurring passage of tidal forces is phased with favourable water movement. This does cause tidal ranges in excess of 1 m on the Tunisian coast and on the northern shores of the Adriatic.

Embarrassing reply 5: Then, why does Venice flood regularly?

Do not accept for an answer that Venice is 'low on the water already'. The waters which flood Venice clearly rise more than just a few centimetres. They occur when the higher tidal ranges of the northern Adriatic combine with weather systems which push in even more water from the South.

To be continued,...

[end this document with a reference to the blackboard tidal challenge]