Lifting a cup of water with an immersion blender

With regard to the "The Puzzling Immersion Hand Blender Effect,"[1] I tried it in my kitchen and find that the effect is very sensitive to the diameter of the container of water. A glass whose diameter is similar to that of the blade guard (as in the photo in Ref. 1) can be readily lifted. However, when a plastic container with about double the diameter was tried, my blender could not lift it, even though the total weight of the new container and water was less than before. (I took care to ensure the spinning blades were fully immersed in both cases.) A significant downward force is felt when the blender is switched on. It is the reaction to that downward force that lifts the glass of water. I suggest that the coupling between the blender and glass is as follows. The water is centrifugally flung away from the curved blades in an outward and upward spiral, so that it corkscrews up the side of the glass. Since the water is pushed upward, the blender is pulled downward (which I counter with my muscles if the blender is not in contact with, say, the bottom of a sink full of water). That explains the force coupling between the blender and the water. Now the upward-traveling water strikes the inner surface of the glass. Because of the surface drag (often called "skin friction"), the water's upward motion is largely arrested. This inelastic collision transfers upward momentum to the glass, thereby lifting it against gravity. However, if the diameter of the container is too large, the water flowing upward crests before it reaches the walls and there is no longer any vertical momentum transfer. (A more powerful blender could deliver greater velocity to the water, thereby explaining the lifting of the saucepan mentioned at the end of Ref. 1.) To test this explanation, I cut the bottom off a plastic cup of narrower diameter than my glass to make a sleeve that I inserted into the water. When the blender was turned on, the sleeve was pushed upward relative to the cup, supporting my hypothesis.

1. C. Chiaverina, "The puzzling immersion hand blender effect," *Phys. Teach.* **52**, 310 (May 2014).

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The puzzling immersion hand blender effect

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Science educator and magician Bob Friedhoffer recently shared a demonstration that he performs with an immersion hand blender and a glass of water. The demo is very simple, yet the physics behind it is not so obvious. He first submerges the blender's blade in a glass of water. With the blade near the bottom of the glass, he turns on the blender and, voilà, lifts the glass and its contents off the table!

Bob reported that he has tried producing the effect with glasses and cups having different shapes and sizes. In some cases lift was achieved; in others it was not. Perhaps not surprisingly, he has also found that some blenders work better than others. He said that a particularly powerful blender once allowed him to pick up a small aluminum sauce pan.

It has been suggested that the Bernoulli effect is responsible for the lift. However, the jury is still out. We would like to hear from readers what they think is behind the effect. Send your ideas to fizzforfun@aol.com.

A glass of water being lifted with an immersion hand blender. The food coloring added to enhance the photo played no role in levitation.

In fact, the correct explanation has nothing to do with the Bernoulli effect and little to do with surface drag. The primary effect is due to suction as the next article convincingly shows.

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Is It Simple to Explain Simple Experiments?

An Unusual Version of the Magdeburg Experiment with a Kitchen Blender

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There are many phenomena, interesting, simple experiments and effects, that await their in-depth explanation from the point of view of physics. Some of them have been well known for a long time but their numbers are increasing, especially with the introduction of new technology in everyday life. In this paper we consider a simple experiment that everyone can perform at home in their kitchen with a handheld blender and a glass of water. When the blender is turned on with the blade close to the bottom, it is possible to lift the glass without holding it in any other way. The explanation of this experiment, however, turned out to be unusually complicated, and we had to consider a large number of different effects. Some of the phenomena that seemed like favorites to explain the effect were ruled out through controlled experiments. The final (in our opinion) explanation turned out to be a variation of one of the famous early experiments in physics—the Magdeburg hemispheres. This experiment demonstrates that interesting physics effects can hide everywhere—even under a kitchen blender.

Previous research of the effect

The effect, to the best of our knowledge, was first presented in the scientific literature by Chiaverina,[1] where there is no explanation given and just a suggestion is mentioned. The paper by Mungan[2] made some suggestions about the nature of the lifting effect without claims to a final explanation. Both papers are short without an in-depth examination of the effect, and the proposed explanations are more hypotheses than proper explanation. The main results from the two papers are:

1. A relatively lightweight glass was lifted.
2. The vessel with water can only be lifted when the blade guard of the blender with the spinning blades inside is placed immediately above the bottom of the vessel.
3. The experiment is only reliably successful when the internal diameter of the vessel is only slightly bigger than the blade guard. With a larger vessel the lifting is harder or even impossible.
4. The water in the blade guard is thrown out by the blade centrifugally to the side and up.
5. The hand holding the blender feels a significant downwards force. It is claimed that the lifting is due to the reaction of the water to that force.

The complexity of explaining the effect is pointed out, despite the apparent simplicity of the experiment:

- In Ref. 1, it is suggested that the effect is possibly due to the circular movement of the liquid and Bernoulli's law, but "the jury is still out." It is hard to figure out exactly what is meant by this explanation. We came up with a possible interpretation—as the water spins it travels at a high velocity; at this speed, according to this interpretation of Bernoulli's law, the pressure in it decreases and a suction effect is created. We cannot be certain if this is what the author of Ref. 1 meant, but Bernoulli's law has a long history of incorrect application along these lines for explaining different effects.[3] We carried out experiments that conclusively showed that the spinning of the water has no influence on the effect.
- In Ref. 2 it is considered that there is friction between the water being thrown out by the blade and the vessel walls. It is suggested that it is this force that lifts the glass, but when the vessel has a large radius the force is insignificant. A controlled experiment is proposed with a small lightweight plastic cylinder placed around the blade in the water. It shows that the cylinder is indeed lifted up, i.e., such a force does exist. The question still remains whether this force is the main factor for lifting vessels with a blender. Lifting large-diameter vessels is hard but still possible. In those cases the vessel walls are quite far away and such an explanation seems unrealistic.

We carried out the experiment under different conditions with three different blenders—a Rohnson R-556 (this was used for most experiments), a Bosch MSM6700, and an older one that had all of its markings erased from years of use. Both new ones have power of 600 W. We performed some controlled experiments to check the suggestions from the previous papers as well as some of our own hypotheses. Ultimately, we got results that led us to the final solution of the problem.

Experiments and results

1. We lifted small vessels with water with a total mass (vessel+water) of about 500 g and small bottom area. These experiments were always successful (Fig. 1).

2. In order to obtain a better evaluation of the lifting force, we lifted progressively heavier vessels holding the blade of the blender immediately above the bottom of the vessel. We made a construction (Fig. 2) with a jar attached to the bottom of the vessel. We filled the jar with lead shot and gradually increased its weight. The maximum mass lifted in those experiments was about 2 kg including the vessel and water.

3. We wanted to examine our interpretation of the suggestion from Ref. 1 regarding the role of Bernoulli's law. According to this idea, the effect of the water on the vessel is carried out by means of the pressure it creates on the bottom. As the water spins, its pressure should decrease and thus the force it applies on the vessel's bottom should decrease. As we mentioned, this explanation is not correct but it is not very easy to figure out exactly how and why it is not correct. It is, however, relatively easy to test it experimentally. To do

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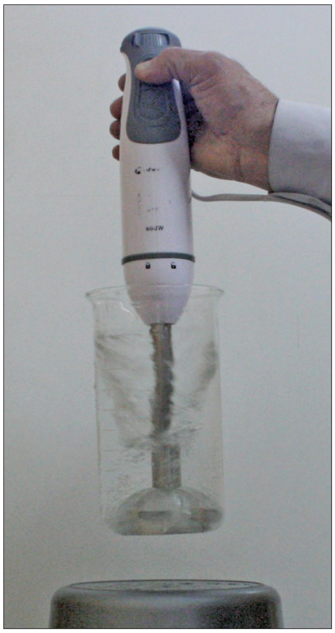

Fig. 1. Lifting a lightweight vessel (mass ~500 g).

Fig. 2. Lifting a heavy vessel (mass ~2 kg).

Fig. 3. Unsuccessful lifting of a plastic cylinder (mass ~200 g).

Fig. 4. A waterless cone under the blade guard.

this we used a set of electronic scales (1-g precision) that we put the vessel on. This kind of scale measures the applied force ("apparent" weight) and gives a reading in units of mass under the assumption of "normal" condition (no buoyancy, no accelerating frame of reference, etc.). Thus a change in the applied downwards force should result in a changed reading of the scales. We first read out the weight of the vessel with still water. Then we spin up the water with the blender and take it out. We read out the weight with the spinning water. It turns out that both readings are the same, i.e., the apparent weight of the water is not affected by it spinning or not. An exact analysis of the forces in a hydrodynamic system is notoriously difficult and in most cases requires much more advanced physics than Bernoulli's law. In any case, this experiment clearly shows that the spinning of the water as a whole has no relevance to the lifting effect.

4. We also carried out a controlled experiment to test the hypothesis from Mungan[2] that the friction between the rising water and the vessel wall are the main factor to the lifting. Figure 3 shows an experiment for lifting a plastic cylinder (diameter 10 cm, height 16 cm, weight 200 g) submerged in a vessel with water. We placed the blade close to the bottom as well as in various other positions. It turned out that the cylinder does not react and does not get lifted. In this experiment we eliminate the bottom of the vessel and only act on the side walls with the upwards rising stream of water. The conclusion is that the friction force that was suggested as the cause of the lifting effect in Mungan[2] is insignificant and cannot lift a heavier cylinder than the one used in Ref. 2 and certainly cannot lift the even heavier vessel with water. We did lift smaller plastic cylinders as in Ref. 2, but their weight is very small. It could be interesting to do a detailed study with cylinders of progressively increasing mass in order to more precisely determine the magnitude of the force in question, but for our purposes it was sufficient to show that it is insignificant.

When carrying out exact quantitative experiments, many factors would have to be taken into account—the flotation force on the cylinders (plastics can have similar density to water), the shape of the walls of the cylinder (smooth or corrugated), the velocity of the water stream, and the amount of water being propelled up (that would very much depend on the model of the blender, the diameter of the vessel, etc.). Since our experiment shows that this force is rather small, we have not carried out more detailed experiments.

5. We carried out an experiment holding the blade far from the bottom and not immediately above it. It turned out that it is impossible to lift the vessel like this, even if it is rather lightweight. During these experiments the hand holding the blender feels a significant force down. Counter to the hypothesis in Mungan,[2] despite this force acting on the blender, the vessel is not lifted, even when it is very light.

When performing this experiment we noticed something unexpected and interesting. As can be seen in Fig. 4, under the blade guard of the blender appears a waterless cone shape. Apparently, the spinning blade expels some of the water from under the blade guard and a zone of lowered pressure forms there. Since the pressure on top of the blade guard is unchanged, it, being larger, creates a downwards force that we feel with our hand. At the lower end of the low-pressure zone it sucks in water. During normal use of the blender for food processing, this suction effect would carry new pieces of food for chopping. This happens when the blender is far from the bottom. Then it is lowered, and the low-pressure zone comes in contact with the bottom and creates a suction effect. Between the blade guard and the bottom is created a localized zone of lowered pressure (partial vacuum), creating a version of sorts of the famous experiment of the Magdeburg hemispheres. Thus it turns out that the blender actually *does not* create a lifting force.

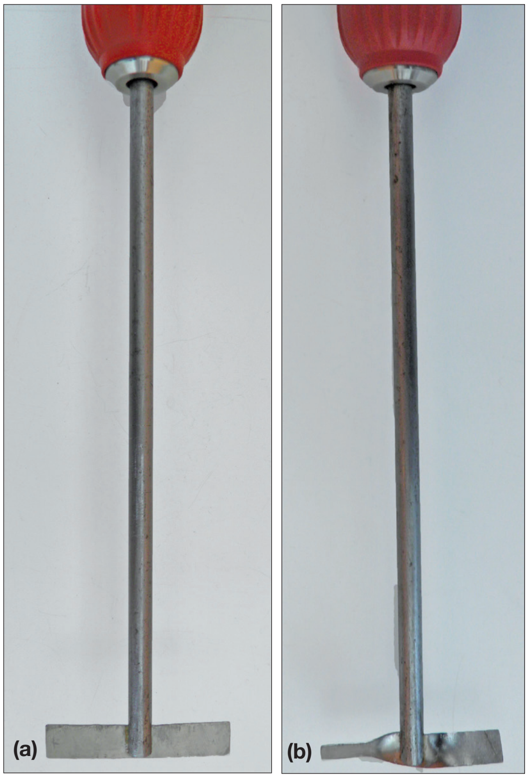

Fig. 5. Spinning plates without a blade guard: (a) flat, (b) propeller shaped.

It creates suction between the blade guard and the bottom. This *could lead to* a lifting, if we actually lift the blender with our hand, but it is in action even when we are not lifting the system. The real lifting force, like in other similar experiments with vacuum, is actually the uncompensated atmospheric pressure on the outside of the bottom. The force we feel in our hand, even when the blender is far from the bottom, is also caused by uncompensated pressure, in this case on the upper surface of the blade guard.

6. In the next experiment we show the importance of the blade guard for the production of the lifting force. For that purpose we made a construction from a metal plate attached to an axle. The plate is put in motion with a handheld power drill (Fig. 5). This device comprises a blender of sorts without the blade guard. We submerge the device and turn on the drill. At that, the water spins fast over the bottom of the vessel. It turns out that the vessel cannot be lifted in this way and stays in place. We conducted the experiment with different plates—some flat [Fig. 5(a)], some bent more like a propeller [Fig. 5(b)], and we placed them at different depths, including immediately above the bottom of the vessel. None of these experiments produced a significant lifting effect, if any. The characteristic waterless cone was not observed under these spinning plates the way it appears under the blade guard of the normal blender. This experiment once again shows that Bernoulli's law does not have a significant contribution to the lifting effect, as we show in Experiment 3. A more important conclusion is that the blade guard plays a decisive role in the creation of the lifting effect. Obviously, there is a complex interaction between the blender's blade, the water movement it creates, and the blade guard. An exact quantitative analysis would require solving a complicated hydrodynamic problem. For our purposes it is enough to know that the blade expels some of the water under the blade guard, a partial vacuum is created, and, specifically when the blender and bottom are close, a suction effect arises that pushes them towards each other. This "sticking" of the two objects allows us to lift the vessel by lifting the blender.

7. We carried out experiments with vessels of different diameter. They showed that vessels with a larger diameter of the bottom (compared to the blade guard) are lifted with more difficulty or not at all. The possible reason for this is that the water in a wider vessel more easily enters the volume under the blade guard and decreases the lifting force. In a narrower vessel the water thrown out by the blade moves up and infringes the flow of water trying to get under the guard. In a wider vessel it is possible for water from the upper layers to go down along the walls and "squeeze" around and under the up-going flow in the center, closer to the blender stem. Aside from that, the wider vessel is less stable and is hard to hold in a vertical position.

   In our experiments with wider vessels we got a better lifting/suction effect when we put the blender closer to the wall of the vessel. We suggest that the proximity of the walls alters the flow of water out of the blade guard and upwards, thus inhibiting the flow from the sides and below and allows for maintaining a better vacuum between the blade guard and the bottom of the vessel.

8. In a larger vessel with water we put a heavy body with a smooth upper surface (the jar with lead shot from Experiment 2). Placing the blender on top of it, we lifted it successfully (Fig. 6). This experiment again shows that the side walls and friction force (proposed in Ref. 2) play no significant part in the lifting effect and that the main effect for the lifting is the suction between the blade guard and the surface it is placed on, which need not be the bottom of the vessel.

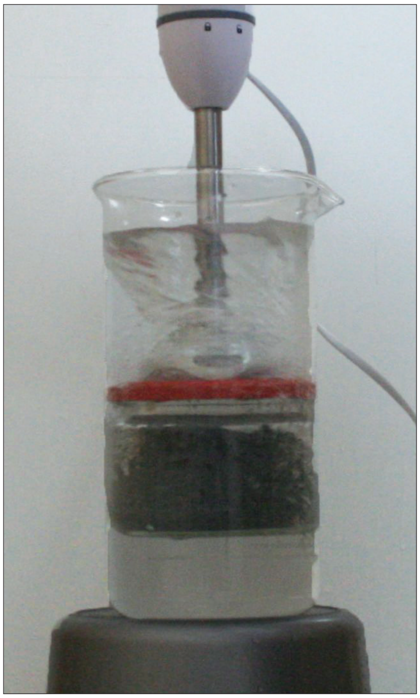

Fig. 6. Lifting a heavy object submerged in water.

9. When preparing cream soup in the last few months, we paid special attention for the eventual arising of the suction effect and its magnitude.

We found that when the blender is positioned at an angle, it does indeed suck in the nearby liquid and the vegetables in it, making the food processing easier. We also noticed that once a thick (highly viscous) liquid is obtained, the suction effect is significantly diminished. In our opinion, this is due to the fact that the more viscous fluid is harder to expel from under the blade guard, and more of it remains there and maintains the pressure.

Conclusions

Based on the analysis of the forces and the controlled experiments, we can make some final conclusions about the decisive reason for the emergence of the lifting effect. In fact, the effect is not necessarily one of lifting but of suction between the blender and the bottom of the vessel. The force on the vessel is towards the blender, which *happens to be* upwards in our case. If a water-resistant blender is brought towards a submerged surface from some other direction, the effect will manifest in that direction. The spinning blade expels some of the water from under the blade guard and creates a zone of lowered pressure. A more detailed examination of the forces involved would be very complicated due to the hydrodynamic nature of the phenomenon. For our purposes it is enough to know that a zone of lowered pressure is created between the blade guard and the bottom of the vessel, and that the two bodies (blender and vessel) are pressed together by the partially uncompensated atmospheric pressure on the outside. It is well known that atmospheric pressure acts on each square centimeter with a force approximately equal to the weight of a body with a mass of 1 kg. The zone under the blade guard has a radius of about 2 cm (area 10 to 15 cm^2). With a full vacuum we could expect a pressing force on the order of 100 N that could lift a mass of about 10 kg. In practice the force is much smaller since the blade cannot fully expel all the water, but the effect is still impressive. The maximum mass that we could lift in our experiments was about 2 kg. It could be interesting to perform the experiment under lower atmospheric pressure (for example, at a high elevation).We would expect the effect being studied to be weaker.

The magnitude of this hydrodynamic suction effect depends on how effectively the water is ejected from the enclosed space. This in turn depends on the construction of the blade and the guard as well as the rotation speed of the blade.

In fact, our experiment is analogous to the well-known historical experiment of the Magdeburg hemispheres—a decreased pressure is created in the space between two bodies and their separation requires a relatively significant outside force. The difference in the case of the blender is that the decrease in pressure is achieved and maintained dynamically, whereas in the Magdeburg experiment and others like it the vacuum is created once and then remains constant.

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