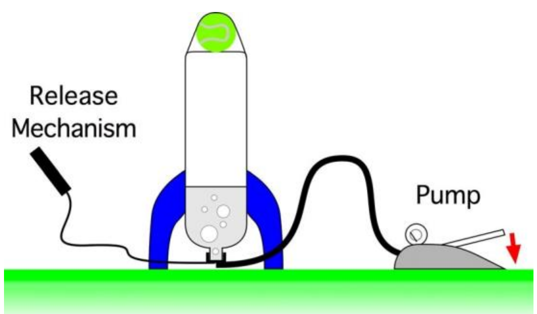
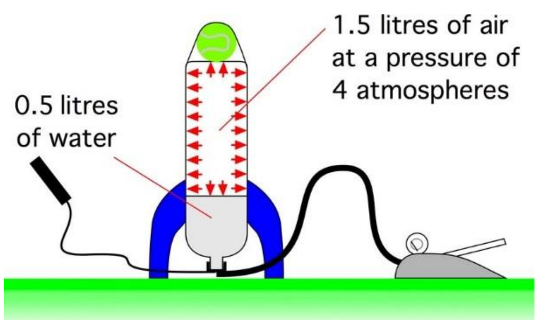
Physics of a water rocket

http://resource.npl.co.uk/docs/educate_explore/water_rockets/wr_booklet_print.pdf

This section is for people who want to understand in general terms what happens during a rocket launch. The left hand column has the time before or after launch in seconds; the middle column shows ‘what’s happening’; and the right hand column contains my commentary. We assume a vertical launch of a two-liter rocket weighing 100 grammes when empty, and quarter filled with water at launch. The speeds and heights quoted are those derived from the water rocket simulator software described in Section 7. Further details of the calculations can be found in Section 10.

Time	What’s Happening	Comments
– 60 s		The rocket is filled, and then placed on its stand. Everyone nearby is warned that the rocket is about to be pressurized, and then pumping commences. As the air is compressed it gets hot, and you should be able to feel this near the exit of the pump. However, as the air bubbles through the water it cools down again, so the air in your water rocket should be close to the temperature of the water

– 30 s

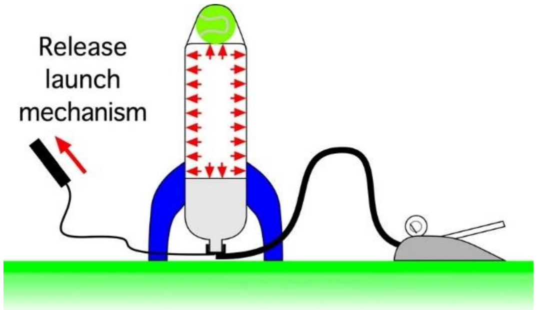


Your chosen launch pressure is reached. To be specific, we’ll assume that the gauge on the foot pump you have used reads 3 atmospheres. Since the pressure before you started was one atmosphere the actual pressure of the air in the bottle is now 4 atmospheres. 1 atmosphere – sometimes called 1 bar, is roughly equivalent to:

- 15 pounds per square inch (psi)
- 2 kilograms per square centimeter
- 100000 pascal (Pa)

The pressurized gas is the energy source for the rocket. A good rocket design will convert the maximum amount of stored energy into kinetic energy of the rocket.

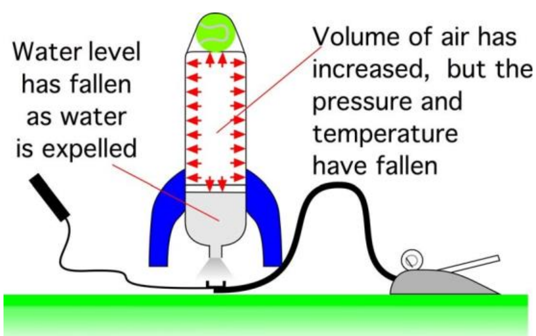
– 5 s **5...4…3…2…1…**



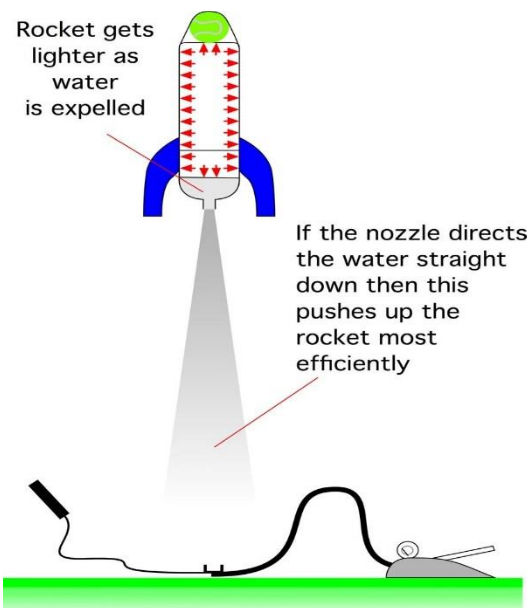
The final launch warning is given and if everything is safe, the launch mechanism is released.

Just before launch the force on the nozzle is very large.

At this point the 500 ml of water weighing 500 g (0.5 kg) makes up most of the mass of the rocket.

+ 0.01 s		As the catch is released, the gas pushes the water out through the nozzle, and the rocket begins to lift off. The pressure of the air begins to fall, and also its temperature drops as the air expands. After 10 milliseconds the speed is still quite slow (around 1 meter per second) because the rocket still has a heavy load of water on board. The rocket has moved less than a centimeter.

+0.1 s

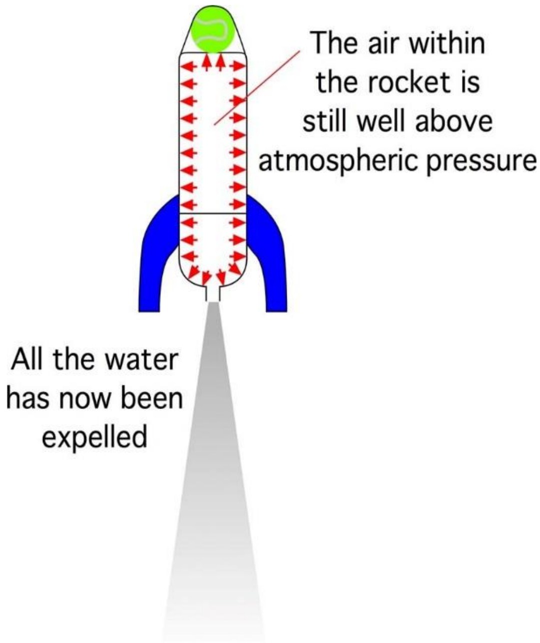


Just under half the water has now left the rocket. The rocket has reached a height of around 0.5 meters and is travelling upwards at approximately 10 meters per second. This corresponds to very large acceleration of around 100 meters per second per second, or roughly 10*g*.

If the nozzle causes water to be sprayed sideways, then this adds nothing to the lift forces.

Frame by frame analysis of a video (Page 26) should show a ‘tube of water’ trailing behind the accelerating rocket.

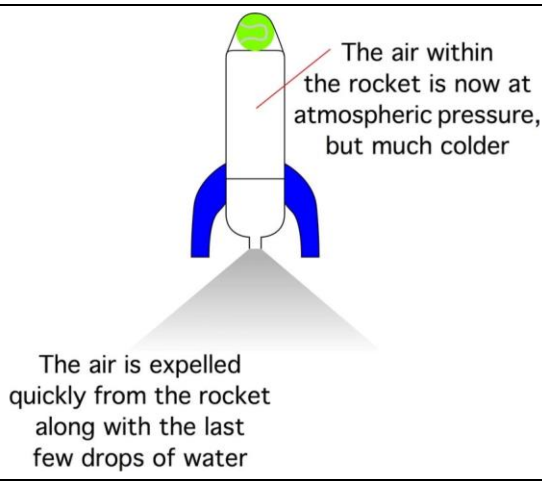
+0.22 s



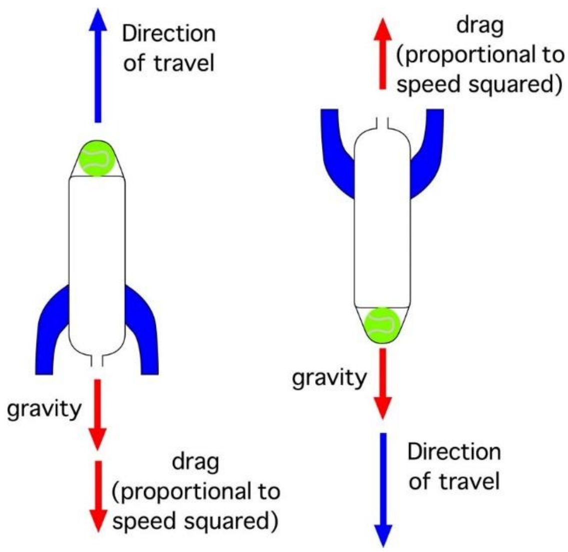
Amazingly all the water has now left the rocket. If you could just imagine emptying 500 ml of water out of a bottle it might easily take 10 seconds. It has now all gone in just under a quarter of a second! The rocket is now travelling at around 26 metres per second.

The pressure has fallen to 2.4 bar from its initial value of 4 bar.

As the air has expanded it cools and is now at approximately –19 °C. But it is still pressurized. However now that the exit is not blocked by water, the air finds it considerably easier to leave the rocket than the water did.

+0.25 s	 	After another 30 milliseconds, the pressurized air has left the rocket giving the rocket a last boost. This boost can have quite a considerable effect because the rocket is now much lighter than it was on launch. At the end of this phase, the rocket is moving at its maximum speed of around 35 meters per second. The rocket now enters the ‘cruise’ or ‘ballistic’ phase of its flight.

+ 0.25 s
to
+ 5.4 s



In this phase of its flight, the only forces acting on the rocket are gravity, and the aerodynamic drag force.

Gravity always acts vertically downward on the rocket, and limits the maximum height to around 34 meters. The rocket then falls, striking the ground after around 5.4 seconds at a speed of approximately 20 meters per second

If the rocket is well designed, the aerodynamic drag always acts to oppose the direction of motion, so the drag acts downwards as the rocket ascends, and upwards, as the rocket descends.

If the rocket is not so well designed, the aerodynamic forces can act on the rocket in other directions and cause it to tumble. If your rocket does this, look at the Section 4 on aerodynamic stability.