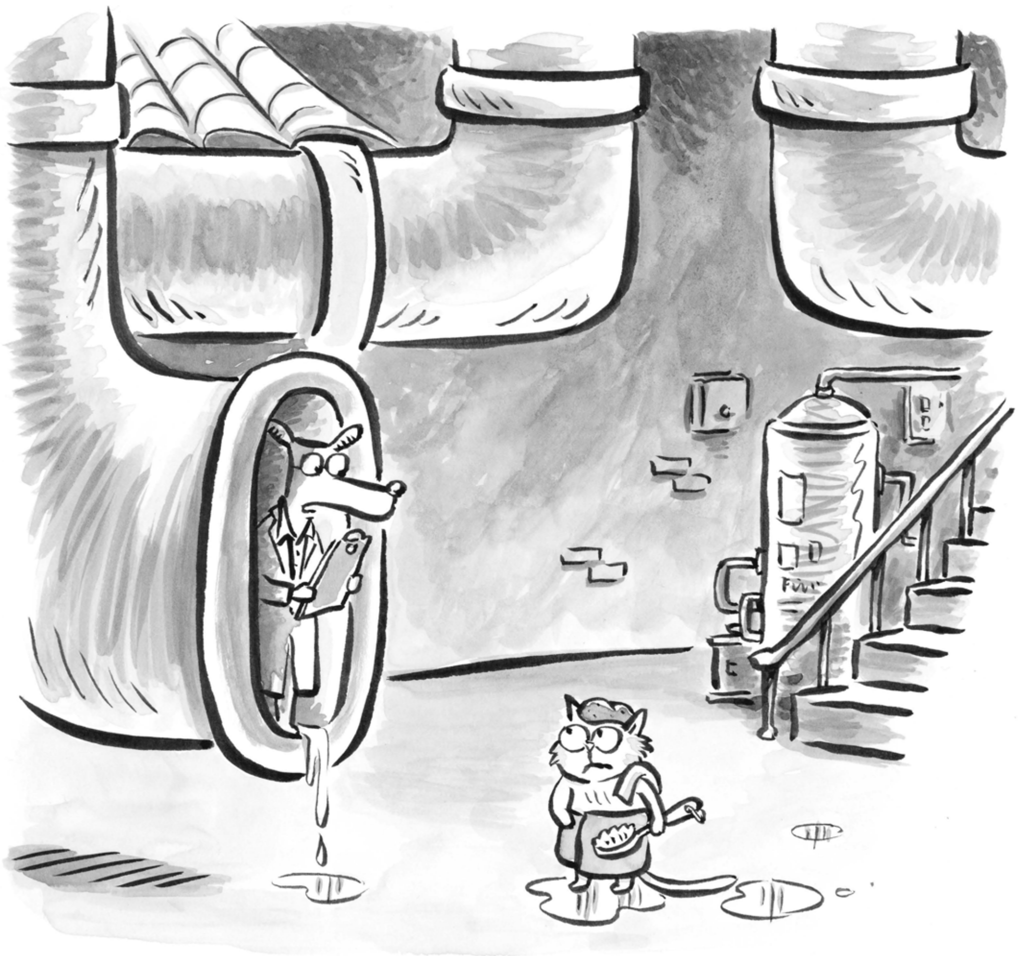


"Well of course you have no water pressure – look at the size of your pipes!"

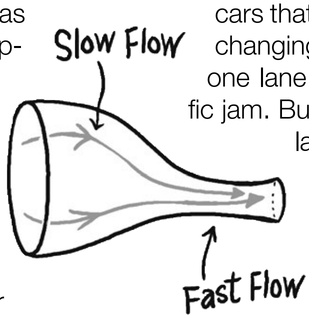
Fluid Flow and Turbulences

Nothing You Should Test on a Highway

What are physicists good for? Well, it depends on the field in which they are specialists. Some can make a night romantic by telling you a lot about stars and galaxies. Others might be able to fix your car or your TV. But what they should all have in common is to be able to calculate the movements of objects if they know the forces acting on them. This is something fundamental that they learn during their first mechanics lectures. If you follow the rules of Newtonian mechanics, you can treat objects as something point like and get, as a first approximation, a good result. Just to mention a few practical examples: You let an apple fall down a well. If you stop your stopwatch at the point at which you hear it hitting the ground you can calculate how deep it is. You can also calculate how to defeat an enemy in a judo fight who is bigger and stronger than you. Or you can calculate the perfect angle to hold your garden hose if you want to reach the flowers which are the furthest away from you (45 degrees). Feel free to think of further applications of the 45 degree solution.

Movements of Gases and Liquids

But what if you want to calculate the movement of something what is definitely not a point-like-object? Something that is more like a giant bunch of objects, all being influenced by an external force, and also interacting with each other? Then you are entering the field of gas/liquid flow and turbulences. It can indeed get so complicated that even the best computers cannot provide perfect solutions. But for certain conditions you can still get some simple results and fundamental laws that the dynamics of fluids follow. The term “fluid” refers to both liquids and gases. Let us take a look at a fluid, say water, flowing through a pipe. If the velocity is not too high and nothing disturbs the flow, the fluid will move in straight lines. We call this a “laminar flow”. This will look similar to a highway with several lanes, filled with cars that all have the same velocity and are not changing lanes. What will happen if suddenly one lane is blocked? Right, we will get a traffic jam. But the reason is not some fundamental law of nature; it is the behavior of us human beings. We are surprised, we slow down, we don’t know what the others will do, we don’t want to collide and so on and so forth. Let us see what water would do. Look at a tube that suddenly gets tighter, as we have shown in the illustration. If you assume it is an incompressible fluid, which water is, you can say that whatever gets pushed into the tube has to come out on the other side. This thought leads to a law called “continuity equation”: The product of a cross section of a tube and the velocity with which the fluid is moving is constant. This means: the narrower the tube, the faster the water! Back to the highway: if all cars would simply go much faster through the part with the blocked lane, there would be no traffic jam. This is of course impractical and dangerous and shows you that you should always crosscheck a physicist’s advice with your experience.



B. Bahr, B. Lemmer, R. Piccolo, *Quirky Quarks*, DOI 10.1007/978-3-662-49509-4_7

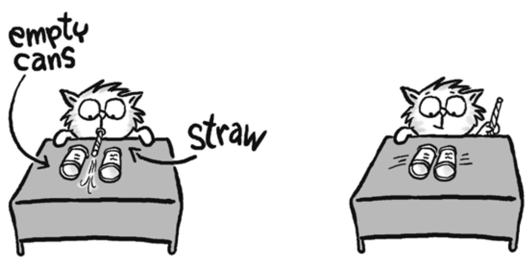
Bernoulli's Equation

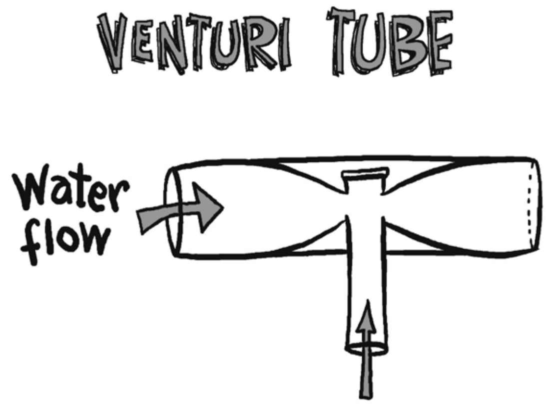
Next to the velocity, we can bring a liquid's pressure (↗[1]) into play. You might know that if you dive deep underwater, the water pressure will increase. In the 18th century, the physicist Daniel Bernoulli derived an equation which connects the height, pressure and velocity for an incompressible flowing fluid with no viscosity. To a certain extent, you can also apply it to compressible fluids, such as gases. Bernoulli's equation states that

$$p + \rho\, g\, h + 1/2\, \rho\, v^2 = constant$$

p is the pressure, ρ the density, g the gravitational acceleration, h the height and v the fluid's velocity. The sum of these three terms will be constant. Let us show you a consequence that might surprise you. You can test it with a little experiment. Place two empty cans on a table and leave a little space between them. Then take a straw tube and blow some air parallel to the cans, the way that Erwin does it. What will happen? Intuitively, one might think that the cans will start repelling each other. Test it.

Did you? The cans started attracting each other. And Bernoulli's equation shows why: Increasing the velocity of the air between the cans has to lower the pressure, as the sum of all terms has to remain constant. If the pressure between the cans is lower than outside the cans, this causes a forces which makes the cans coming closer. Bernoulli's equation plays an essential role in the answer to the question "Why does a plane fly?" (↗[2]). Another nice application is the Venturi tube. The tube has a more narrow part in which the liquid has to flow faster and causes a pressure drop. If you connect a second tube to that part, you can inject a second fluid via the depression, for instance. Such Venturi tubes are used to mix gasoline and air within a combustion engine or to add air to wine to make it taste better.



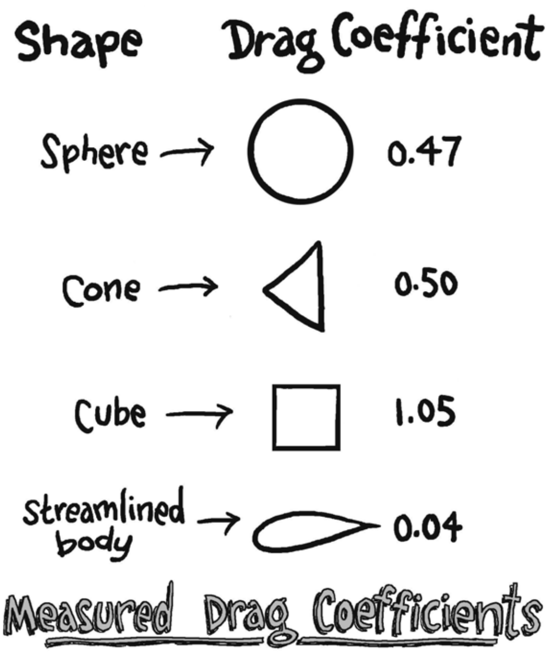


Friction, Viscosity and Turbulences

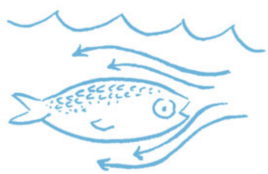
Often fluids are not as ideal as we have considered them so far. There is indeed a friction within the fluids which leads to a resistance against a flow. It can be quantified as the "viscosity" of a liquid and tells us "how thick a liquid is". Honey, for instance, has a large viscosity while water does not. You can read more about it in the chapter about superfluids (↗[3]).

↗[1]: *"Vacuum and Air Pressure" on page 23*
↗[2]: *"Why Does a Plane Fly?" on page 31*
↗[3]: *"Superfluidity" on page 183*

The flow of a liquid does not only have to deal with the internal friction of a liquid, but also with the friction of anything that stands in the fluids way. Think of a car driving fast on the highway. The air will flow around the car with a certain velocity. Due to the friction between the air and the car, the car experiences a certain force. This drag force increases with the velocity of the air (or the car) squared. Twice the speed, four times the resistance! And that force can be quite annoying and leads to a higher consumption of fuel. If you want to minimize it, you can either go slow or, probably more convenient, optimize the shape of your car. The shape determines the factor by which the drag force increases with the velocity squared: the drag coefficient c. Companies put a lot of effort into optimizations of the designs of cars, trains and other vehicles. You can vary your own shape when the next strong wind blows and test the drag coefficients that we provided.



So far we considered the flows of liquids as laminar. But if the velocities of fluids get too high, laminar flows become turbulent. This means that the fluid's pressure and flow velocity changes rapidly with time and space. The moment at which the transition between laminar and turbulent motions occurs depends on the fluids viscosity. The larger the viscosity, the higher the velocity can be without causing turbulences. Turbulences are also called "chaotic". This means that small changes in the conditions of a system cause large changes in its behavior. Think of a river with a laminar water flow into which you put your finger. The water will keep flowing in a laminar way around it. And now think instead of a turbulent flow, such as the flow of milk that you add to your coffee.



You can try to pour milk into a cup of coffee the same way several times, but the swirling patterns will always be different. That is what physicists call chaotic. A general description of fluid motions can be calculated via the "Navier–Stokes equations", which are quite complicated. They contain all the special cases that we have mentioned in the text. On the one hand, they are quite powerful. On the other hand, they are very hard to solve. Calculating turbulent fluid motions requires large computational efforts. If it was not that complicated, the weather forecasts would also be more reliable.