Contact Forces from Fluids

Pressure and Buoyancy

Clicker Channel D

Australian National University

Student Experience of Learning and Teaching (SELT)

- Learning and Teaching evaluations for this course are being run online
- Links to the online surveys will be sent to your ANU student email account
- Look out for the emails from ‘ANU Student Evaluations’
- For information and past results go to: http://unistats.anu.edu.au/surveys/selt/

This week's homework

- Is due in near the end of the break -
  Sunday 23rd April.
- You need to submit a new CPR question and mark last week's one.
- If you won't have internet access over the break, you should try and do it before you go.

Contact forces

- We’ve talked about normal forces and friction (when solid touches solid).
- We also briefly mentioned drag (fluid friction)
- Now we’re going to look more generally at the forces when a fluid (gas or liquid) touches something.

Hit by cricket ball

- Let’s imagine you are hit by a fast-bowled cricket ball.
- It would hurt.
- What force does it apply to you?

Velocity 40 m/s

Mass 160 g

How do we work this out?

- We know the before and after states (moving ball, uninjured person turns to stationary ball and injured person).
- As the ball stops, an impulse I (force times time) equal to its initial momentum must have been applied to it.
- $I = mv = F\Delta t$

So Δt is crucial.

- How long did it take the ball to slow to a halt?
- Let's say 1/10 sec.
- In this case,

$$F = \frac{mv}{\Delta t} = \frac{0.16 \times 40}{0.1} = 64N$$

Impacts from Air Molecules

- You are being hit all the time by vast number of air molecules.
- Each is pretty small, but they are going fast (around 60 km/hr) and there are an awful lot of them.
- Over the same area as the cricket ball hits you, the air molecule collisions apply a force of around 160 N!

More than twice the force of the cricket ball!

- And this applies to all parts of your body, all the time!
- It is called “Air pressure”
- Why aren’t you bruised black and blue by this endless force?

Uniformity

- It's presumably because the force is applied so evenly, and the fluids inside your body apply equal and opposite outward forces.
- If you take away air pressure, e.g. with a suction cap, you really see the effect of this force.

Simulation

- http://phet.colorado.edu/en/simulation/gas-properties

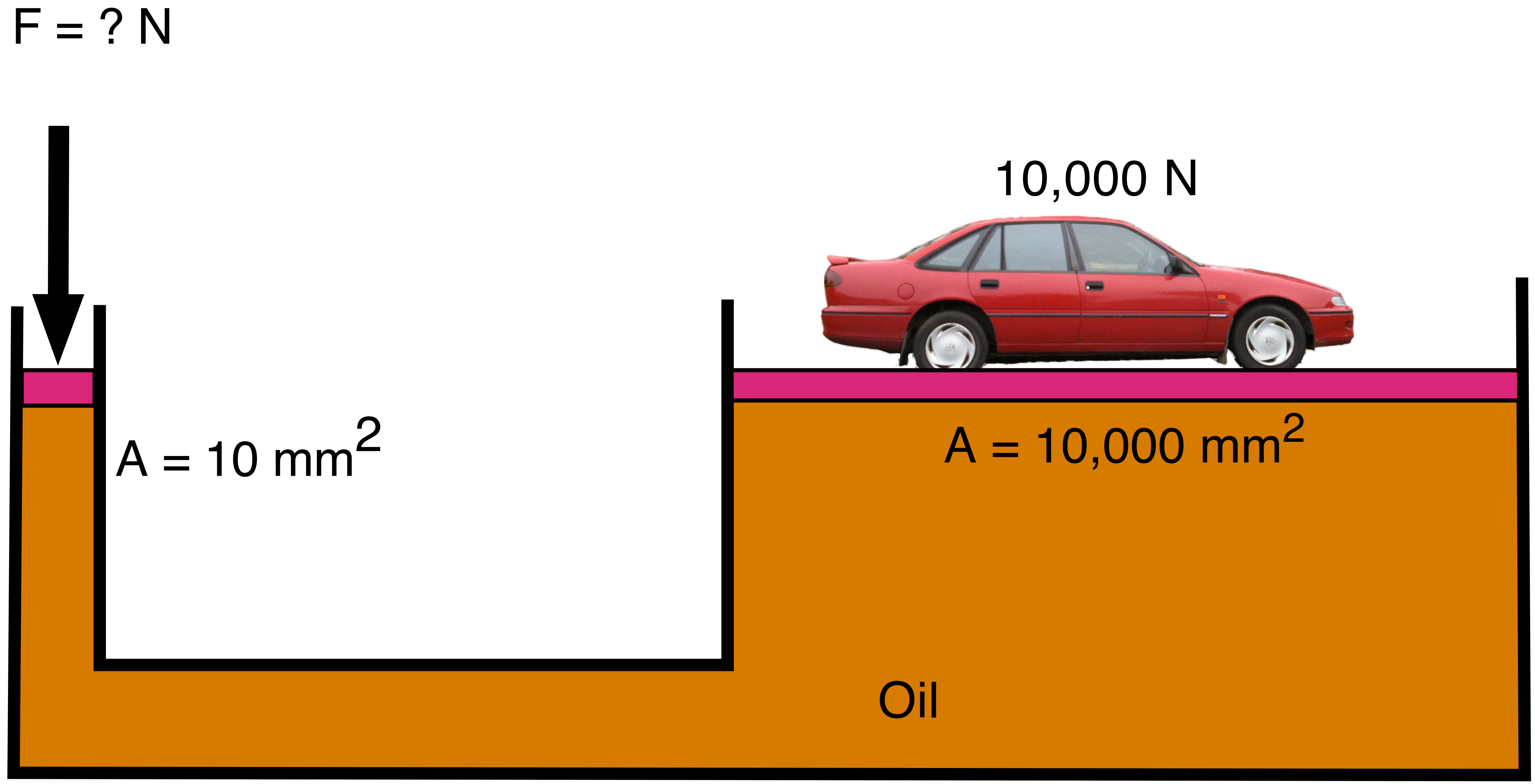
This is called “Pressure”

- And it has rather strange properties.
- It applies to every surface immersed in a fluid.
- The force depends only on the area of the surface.
- The force acts in all directions!

Atmospheric pressure

- is around 100,000 Pascals.
- A Pascal is 1 N m^{-2}. i.e. the force exerted on a one square metre area.

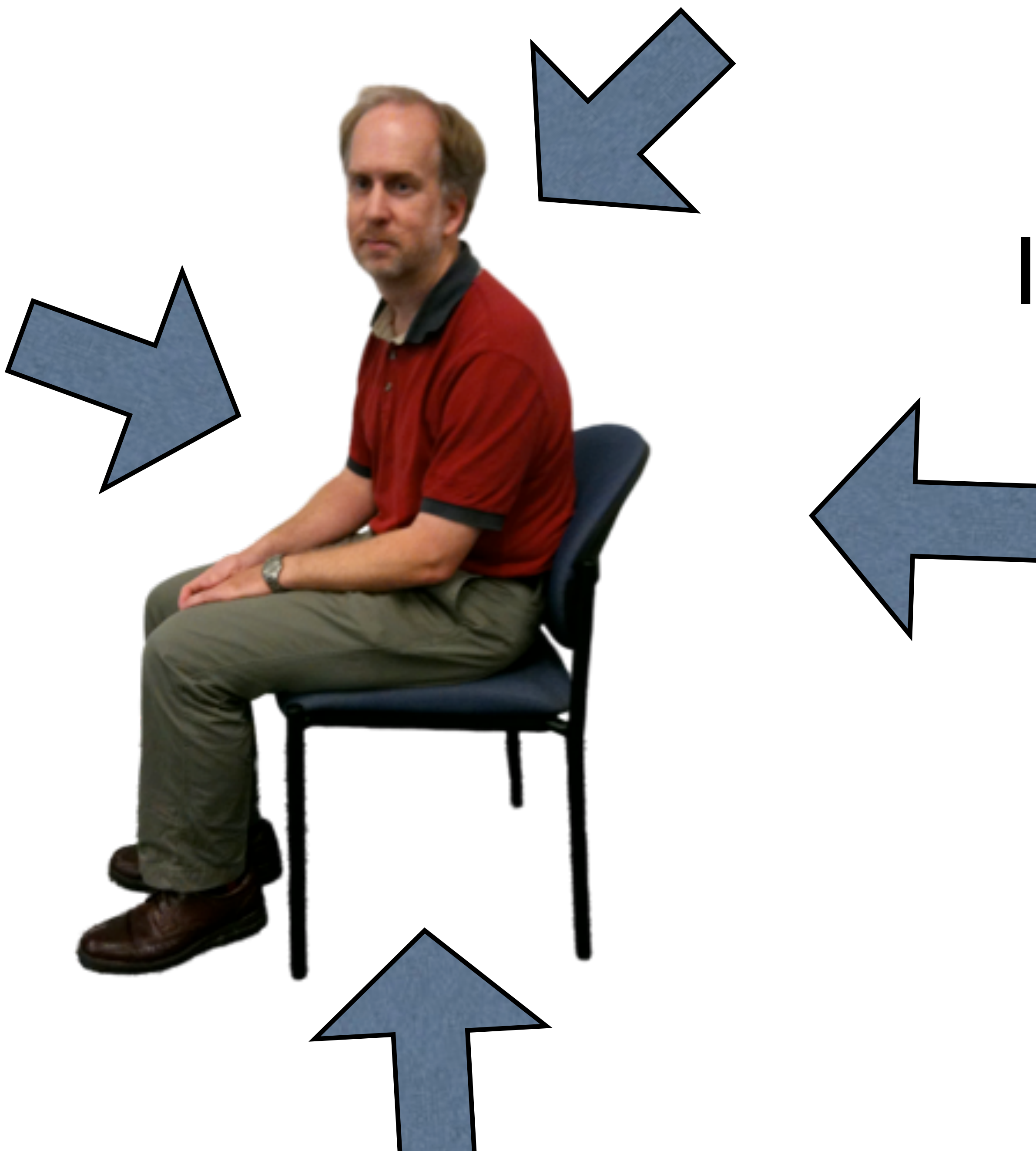
A container is filled with oil and fitted on both ends with pistons. The area of the left piston is 10 mm^2; that of the right piston is 10,000 mm^2. What force must be exerted on the left piston to keep the 10,000 N car on the right at the same height?



Answer

- 10 N.
- Pressure is the same. As otherwise Oil would flow from one side to the other.
- So same force per unit area.
- Area is much smaller so force is much less.

Is pressure force equal in all directions?



If the pressure is the same everywhere, then yes.
Any object has an equal area in each direction and its opposite

Air slab

- Take a particular bit of air in this room.
- Any bit will do.
- Choose it as your system.
- It has a gravitational force downwards.
- Yet it doesn't fall downwards. Why not?

Pressure gradient

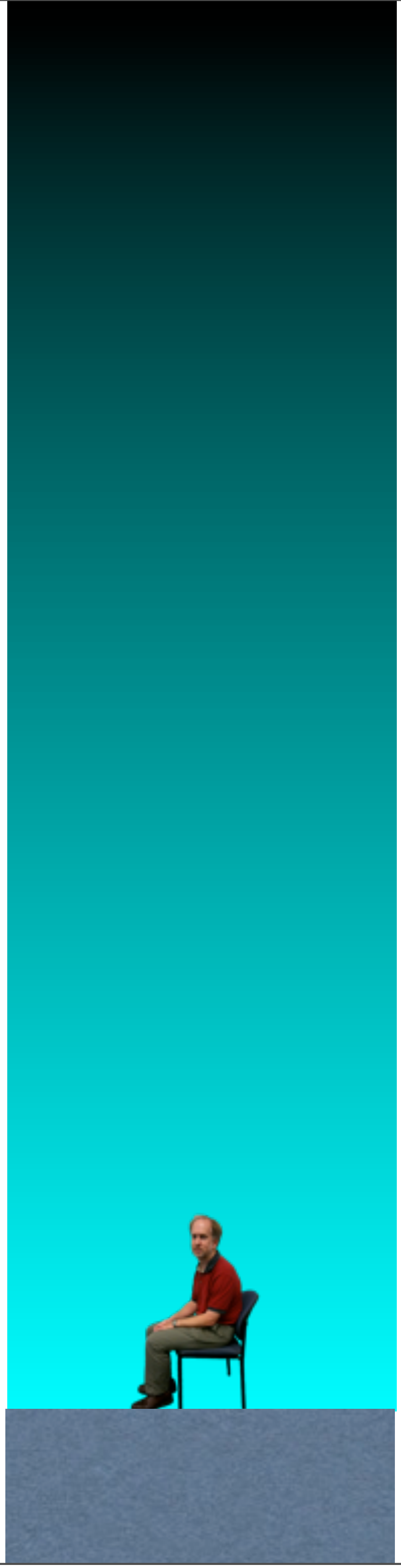
- The pressure in any fluid must increase downwards.
- This offsets the weight of the fluid.
- It is a small percentage change, but because pressure forces are so enormous, it can have a big effect.

What causes this pressure increase?

- The fluid could be denser lower down (so more atoms are available to fit you).
- Or it could be hotter (same number of atoms, but they are moving faster when they hit you).

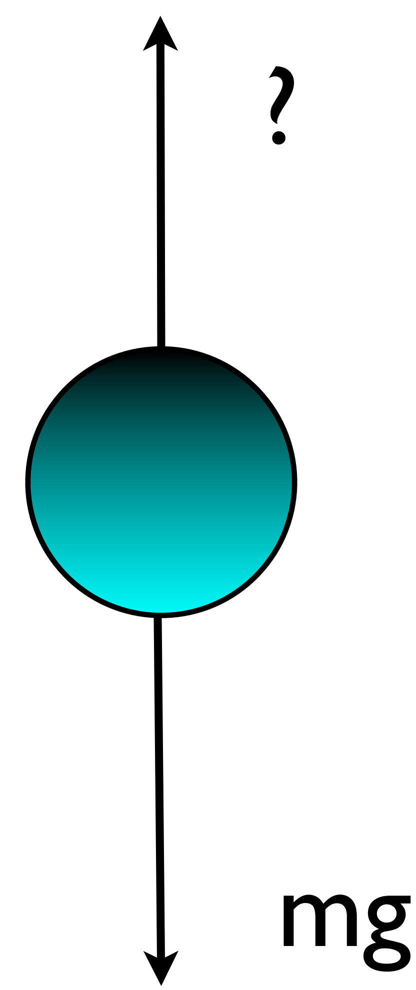
Whole mass of air...

- Consider the whole column of air above you.
- Choose it as your system.
- It's not moving up or down/ So forces must balance on it.
- Draw a free-body diagram for the air.



There must be a balancing force

- What is it?

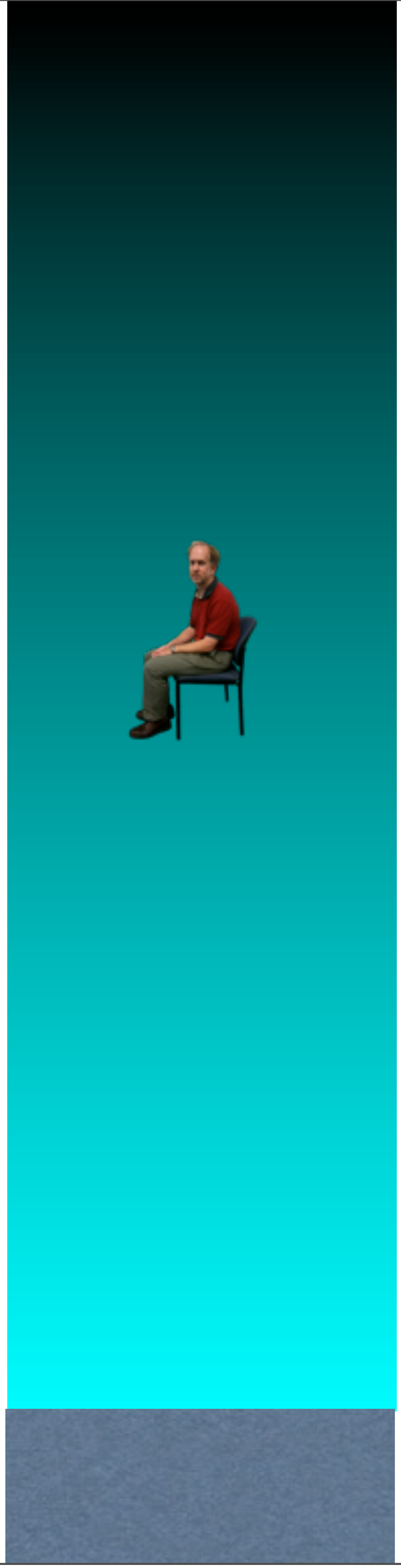


Pressure from the ground!

- Solids can exert pressure too!
- The bottom of this air column is being constantly hit by the vibrating atoms of the ground.
- And by Newton's third law, the force that the Earth exerts on the air is equal and opposite to the force the air exerts on the ground.

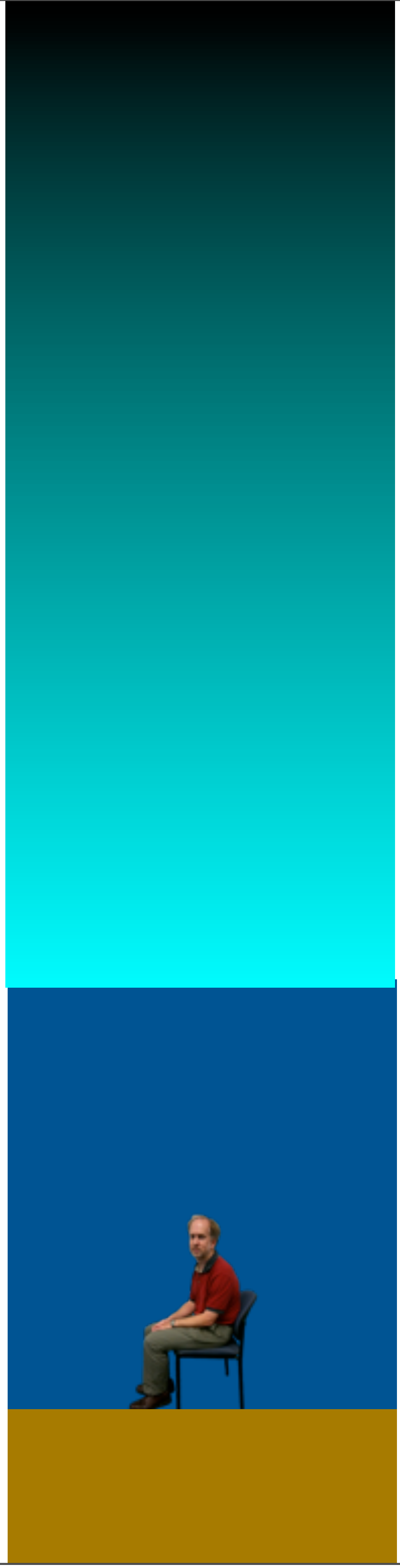
Air column!

- So the air pressure will be equal to the weight of all the air above you.
- That's another way of seeing why air pressure drops as you go up - there is less air above you!



Pressure underwater

- Now the pressure is that of all the air and water above you!
- As water is 1000 times denser than air, the pressure increases very dramatically.
- 10m of water is enough to double the pressure of the air.



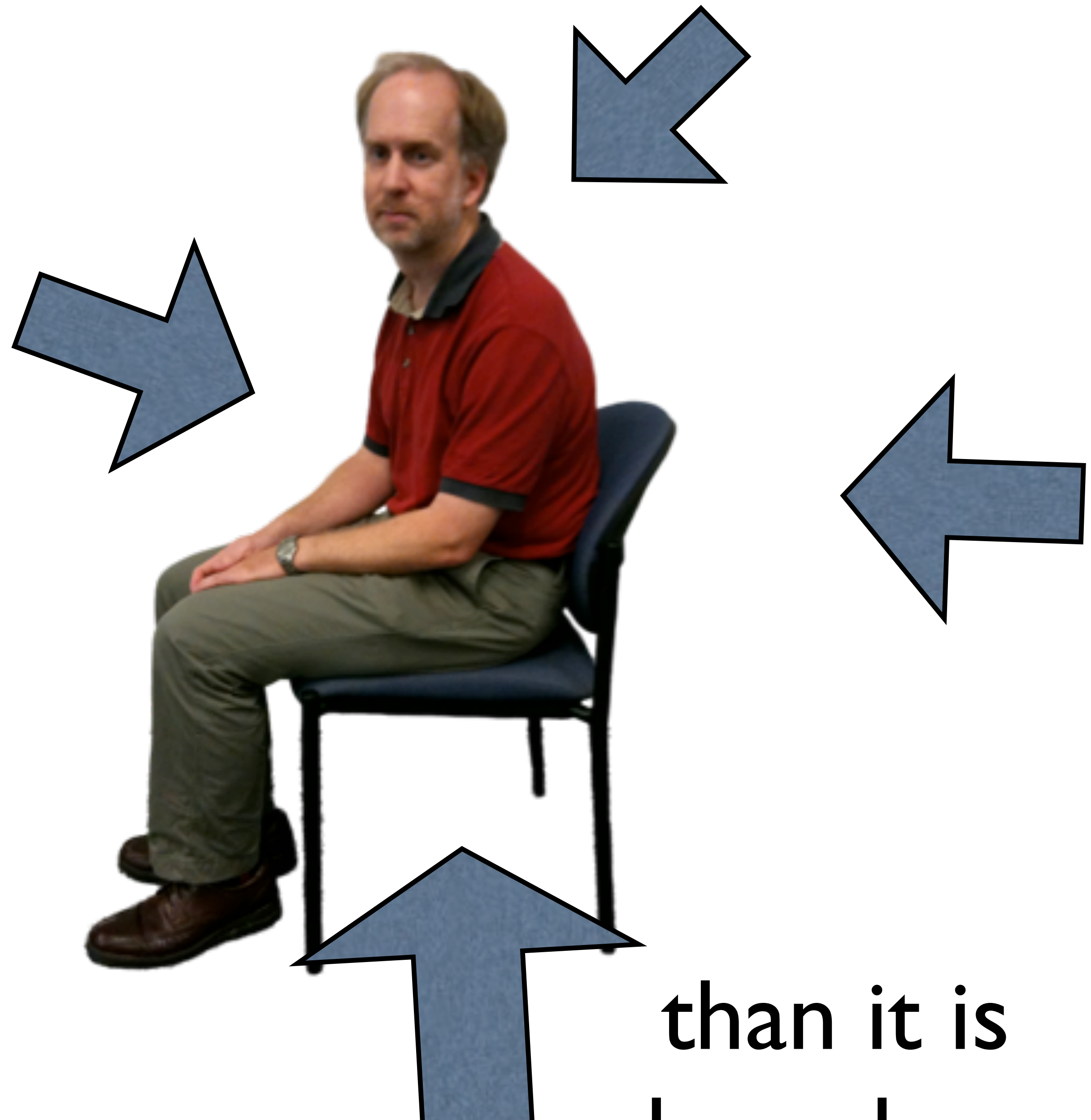
Hugh implications for divers

For example

- Air needs to be fed to you at the ambient pressure, or you couldn’t breath it.
- So when you are 10m down, it must be at double the surface pressure, and so it twice as dense as normal.
- So your air tank empties twice as fast as just below the surface.
- The air in your buoyancy vest compresses to half its size, so it no longer counteracts your weights. You need to add more air.

Net pressure force

- Because of this pressure gradient, there will be a net upward pressure force on any object immersed in a fluid.



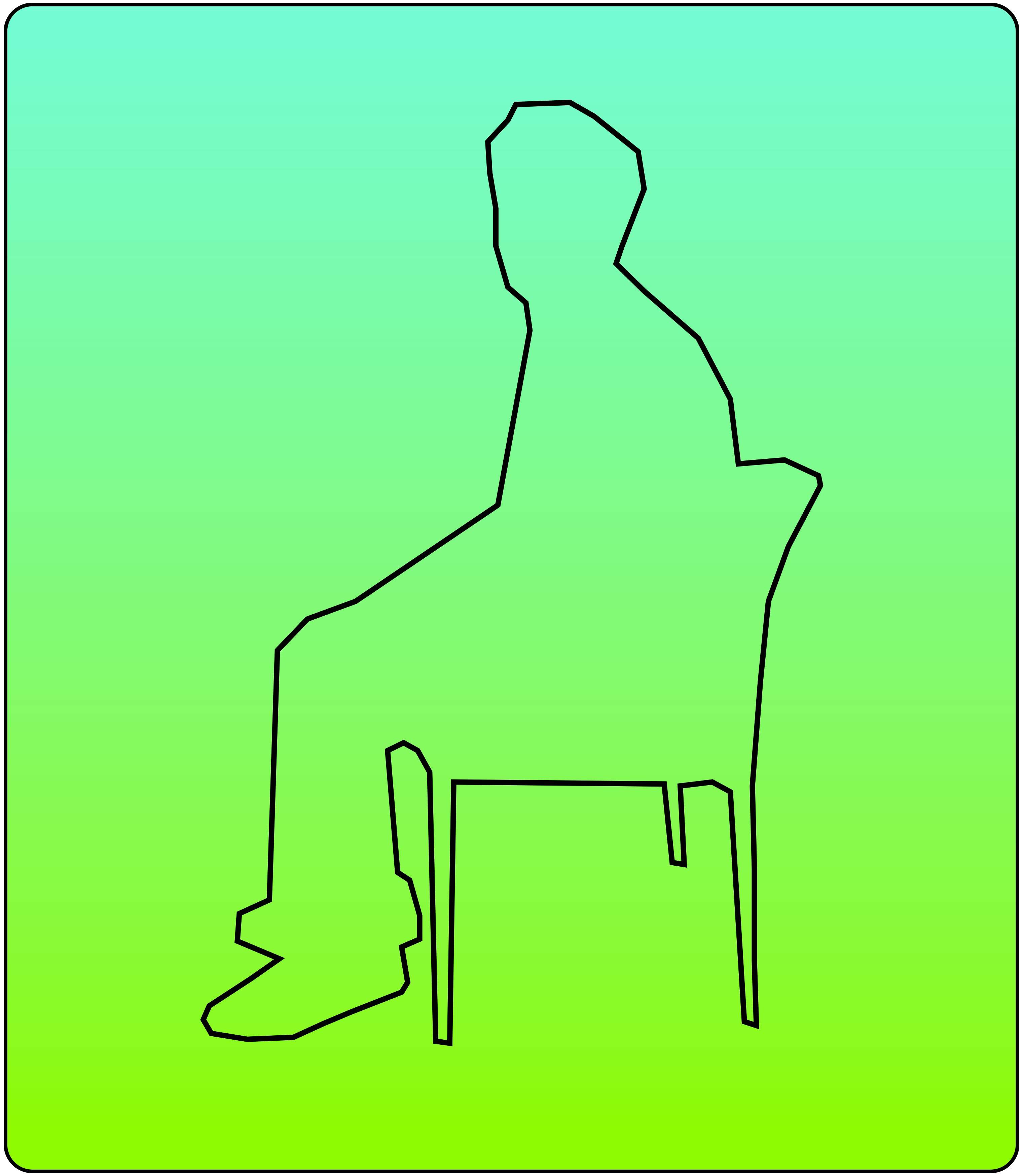
This force is called buoyancy

- How can we work it out?
- You could derive the equation for how pressure varies with height.
- And then integrate over the whole surface to work out the net force.
- But - there is a cunning trick which makes it MUCH easier.

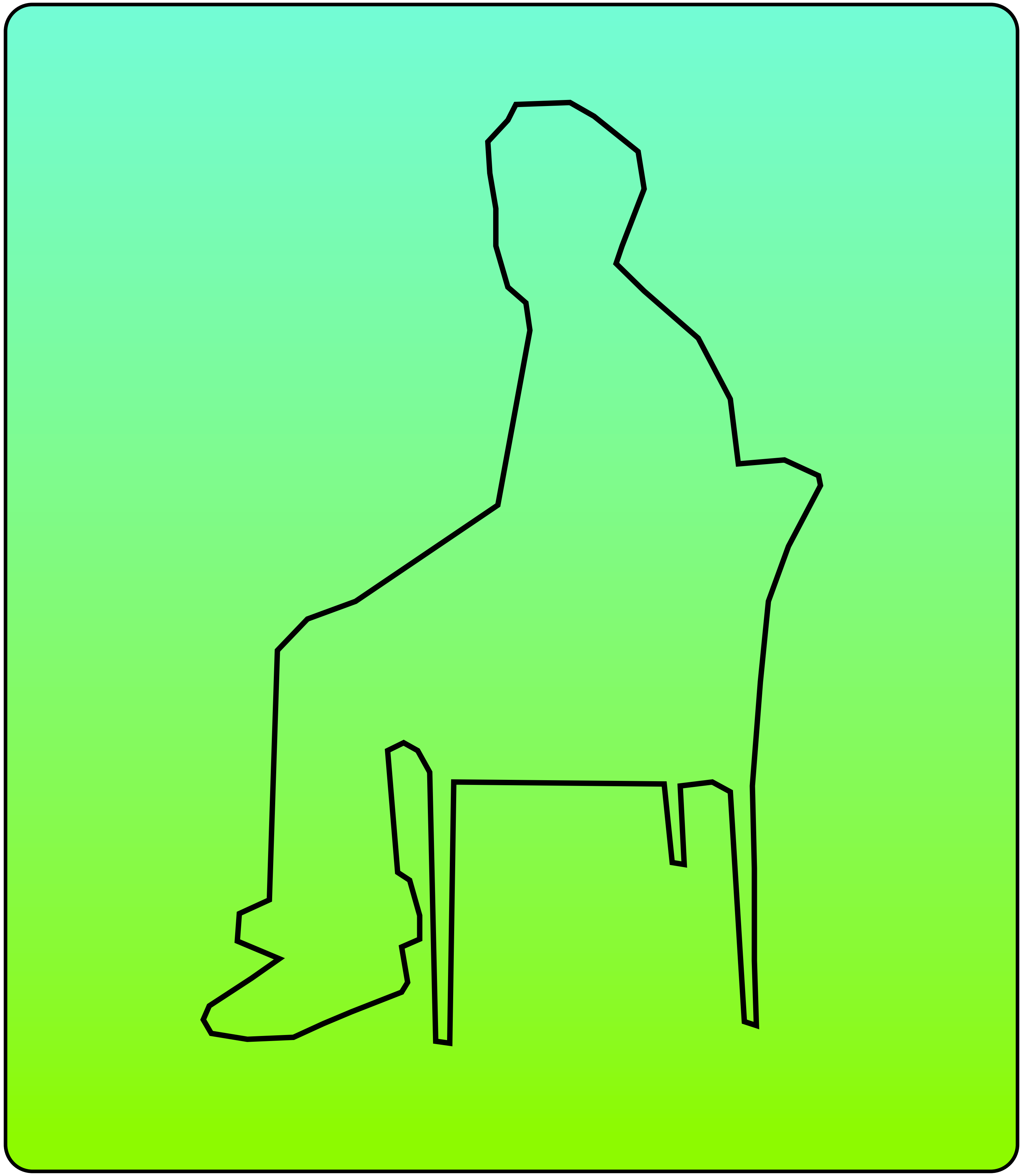
Trick

Take an object immersed is a fluid (which has a pressure gradient). What is the net force on it? Very hard to calculate

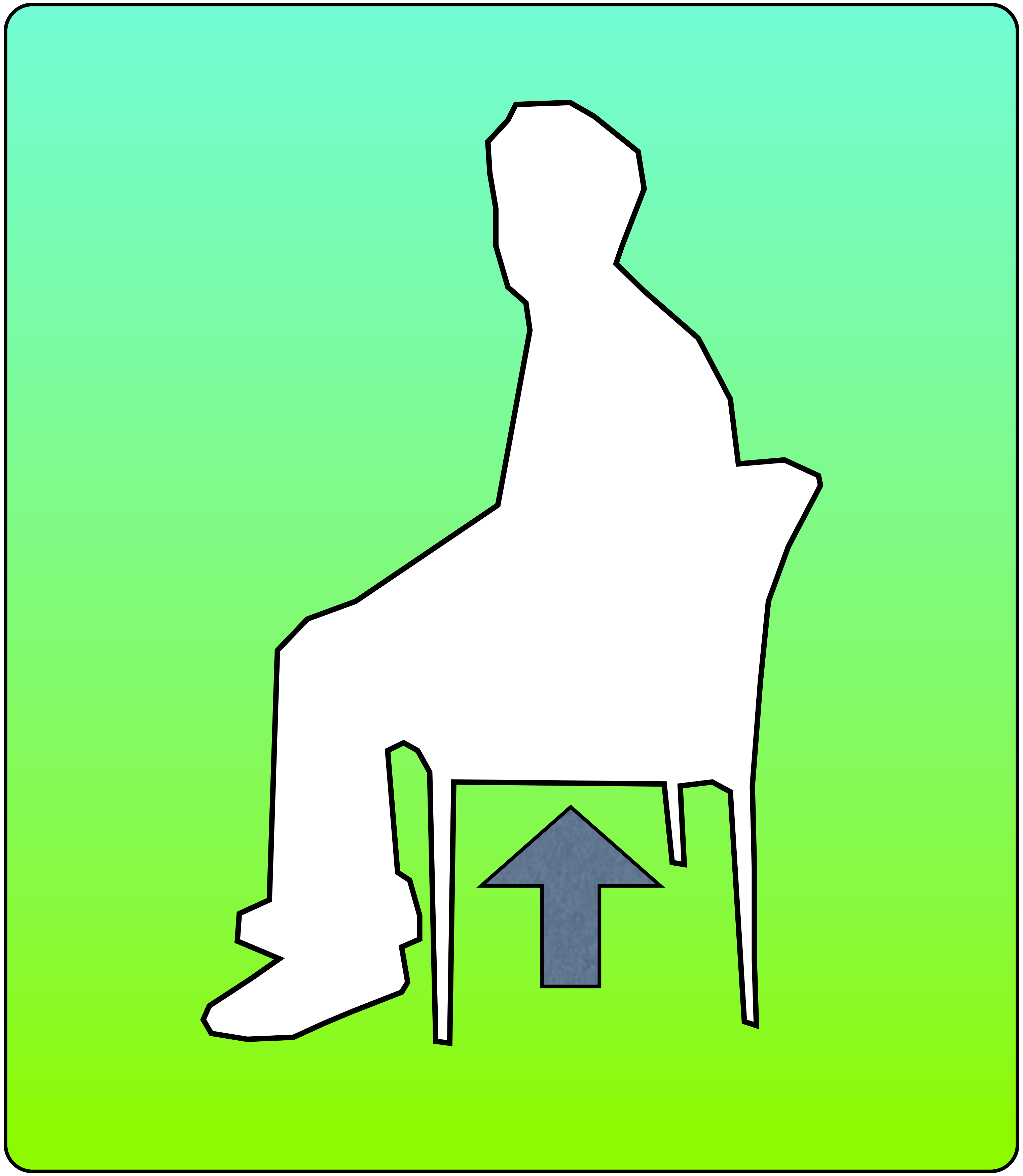
Replace the object



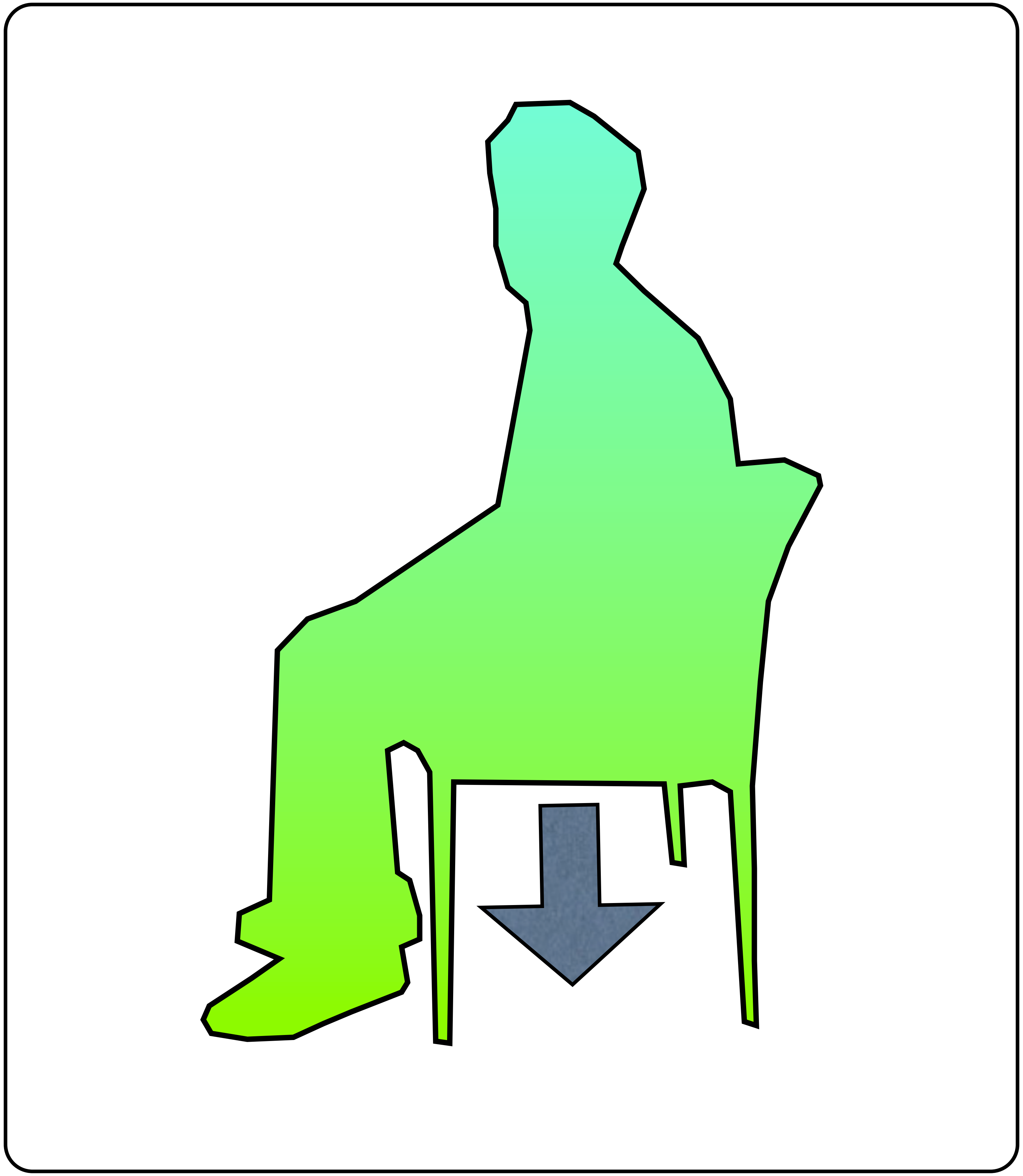
with an identical shaped bit of the fluid



We can pick any system we like - let's choose this rather odd shaped one. This bit of the fluid isn't going to move, rise or sink, so the net pressure force on it must be exactly enough to balance its gravity.



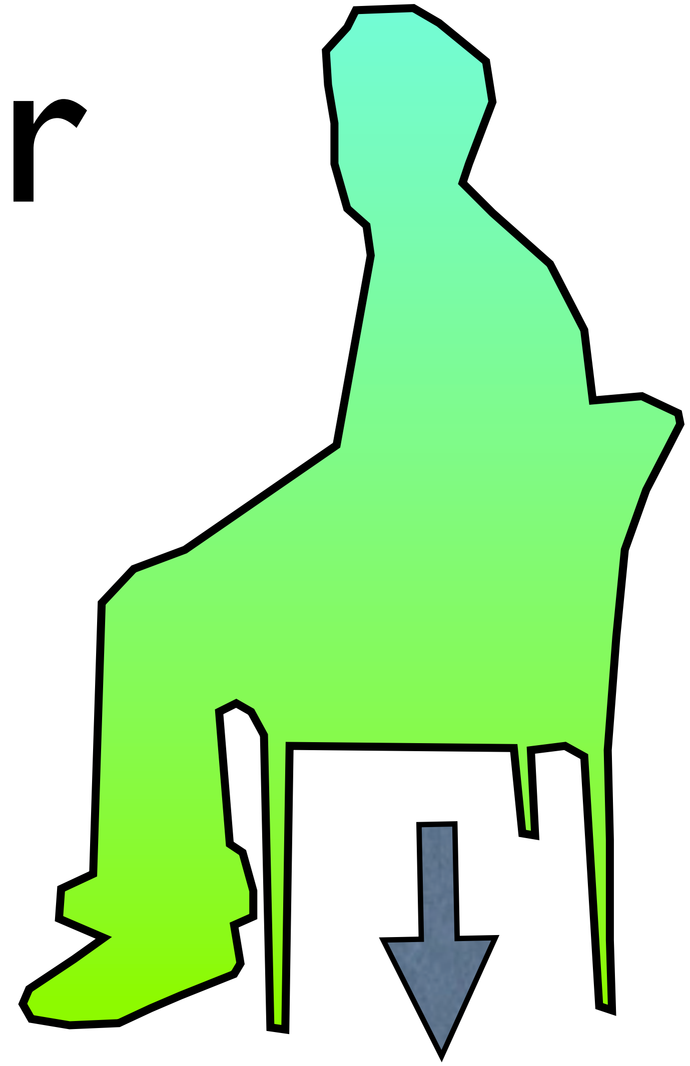
So the net force exerted by pressure on a surface with this shape...



will be equal and opposite the weight of this shape, were it filled with the fluid.

The Answer

Immerse an object in a fluid, and the net buoyancy force on it will be...



Equal and opposite to the weight of the fluid it displaced.

Numerical Example

- What is the buoyant force on me as I stand here? How much does it reduce my effective weight?
- We need to know my volume, and the density of air.
- Density of air is about 1.2 kg m^{-3}.
- I don't know my volume but I do know my mass (75kg). As I am mostly made of water (density 1000 kg m^{-3}), this means my volume must be ~75/1000 = 0.075 m^3.

How much air do I displace?

- So I am displacing 0.075 m^3 of air.
- The mass of this air is 0.075x1.2=0.09 kg.
- So the net buoyant force on me is mg = 0.09x9.8 = 0.88 N upward.
- Which is 0.88/(9.8x75) = 0.12% of my weight. Not big.

In sea-water...

- Density of seawater is around 1030 kg m^{-3}.
- So if I were immersed in seawater, the buoyant force would be ρVg = 1030x0.075x9.8 = 757 N, which is more than the gravity on me (75x9.8 =737 N)

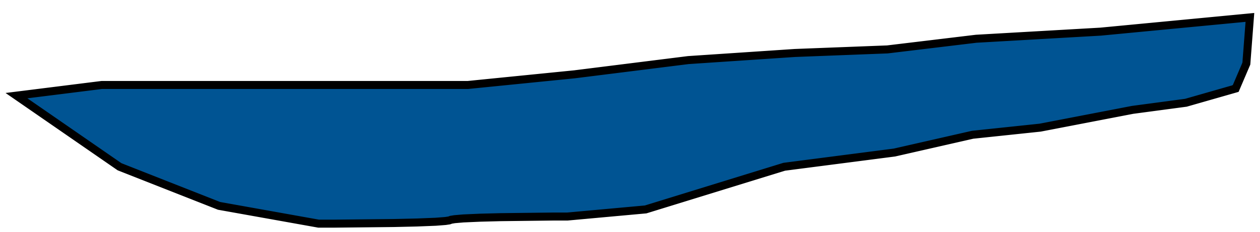
This is known as "floating"

Floating

- An object will float if the mass of fluid it displaces in equal to the mass of the object.
- The force to oppose gravity is due to greater impacts from fluid particles on the bottom than on the top.

How does it float?

The mass of the whole ship,
above and below the water line...



must equal the mass of the water displaced. Which is the volume of the ship below the water line, times the density of water.

Canal

- A 200 tonne ship enters the lock of a canal. The fit between the sides of the lock and the ship is tight to that the weight of the water left in the lock after it closes is much less than 200 tonnes.
- Can the ship still float if the quantity of water left in the lock is much less than the ship's weight?

Answer

- Yes - it can float. What matters is not the weight of the water left in the lock, but the weight of the water forces out of the lock by the ship. As long as the density of the ship is less than that of water and the water gets to the waterline, it floats.

Ice Cubes

- Two identical glasses are filled to the same level with water. One of the two glasses has ice cubes floating in it. Which weighs more?

Answer

- The ice cubes displace exactly their own weight in water, so the two glasses weigh the same.

Boat Boulder

- A boat carrying a large boulder is floating on a lake. The boulder is thrown overboard and sinks. The water level in the lake (with respect to the shore) does what?

Answer

- When it is inside the boat, the boulder displaces its weight in water. When it is thrown overboard, it only displaces its volume in water, so the water level of the lake with respect to the shore goes down.

Key Points

- Fluids exert contact forces too, which are called pressure.
- This pressure is typically enormous.
- The pressure decreases as you go up, so an object in a fluid experiences a net upward force, called buoyancy.
- The buoyant force is equal to the weight of the fluid displaced.