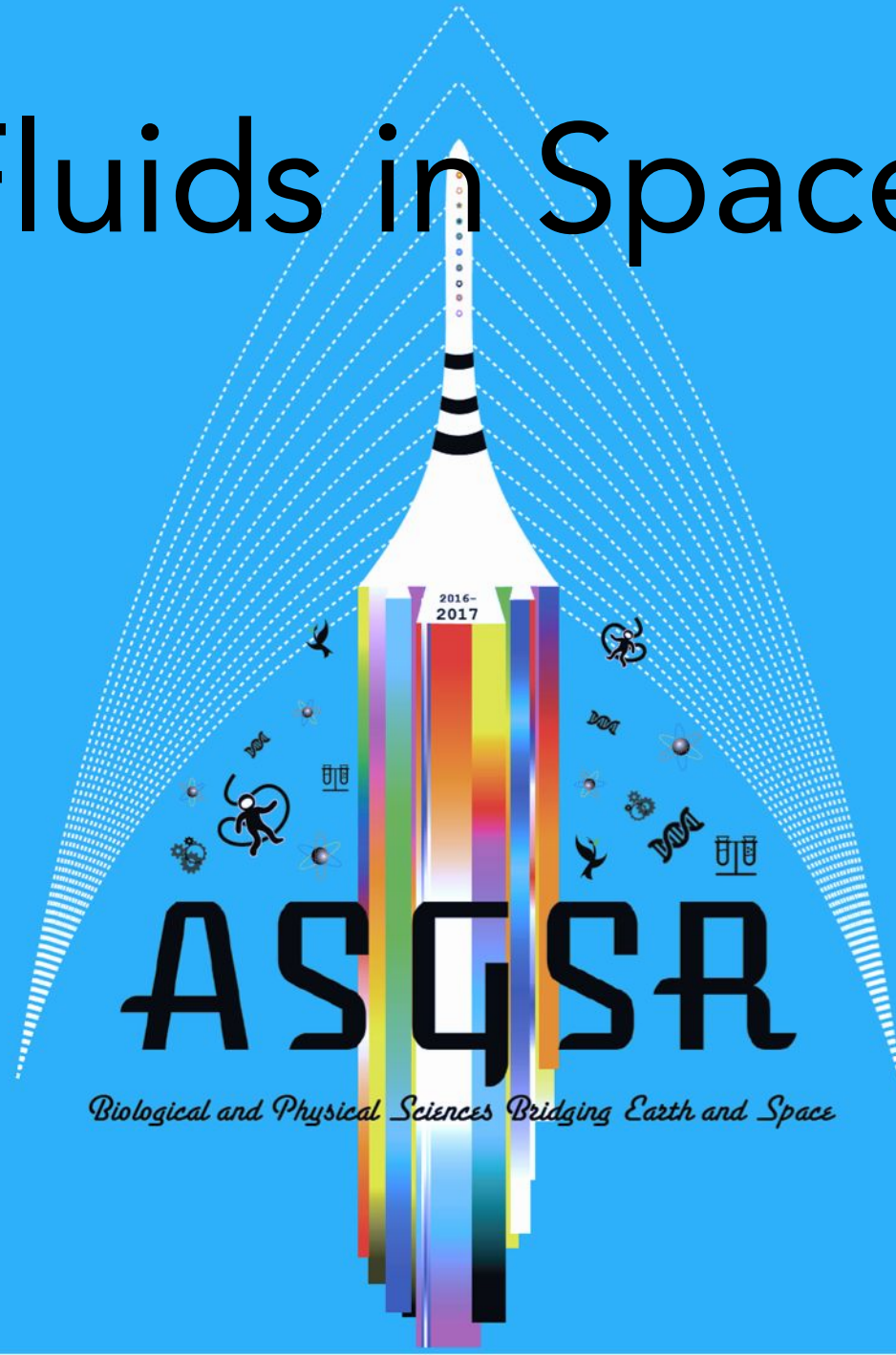


Fluids in Space



Biological and Physical Sciences Bridging Earth and Space

Fluid: A substance that flows and conforms to the shape of its container

Liquid: An incompressible fluid with higher density

Gas: A compressible fluid with relatively low density



Fluid Properties

- **Density:** How heavy the fluid is
- **Viscosity:** How easy the fluid flows
- **Surface Tension:** Attraction between fluid molecules

FLUIDS AND FORCES



Fluids flow by definition, meaning that many forces cause them to move. Therefore, equation of motion is complicated:

$$\underbrace{\rho \left(\underbrace{\frac{\partial \mathbf{v}}{\partial t}}_{\text{Unsteady acceleration}} + \underbrace{\mathbf{v} \cdot \nabla \mathbf{v}}_{\text{Convective acceleration}} \right)}_{\text{Inertia (per volume)}} = \underbrace{-\nabla p}_{\text{Pressure gradient}} + \underbrace{\mu \nabla^2 \mathbf{v}}_{\text{Viscosity}} + \underbrace{\mathbf{f}}_{\text{Other body forces}} \quad \underbrace{\hspace{10em}}_{\text{Divergence of stress}}$$

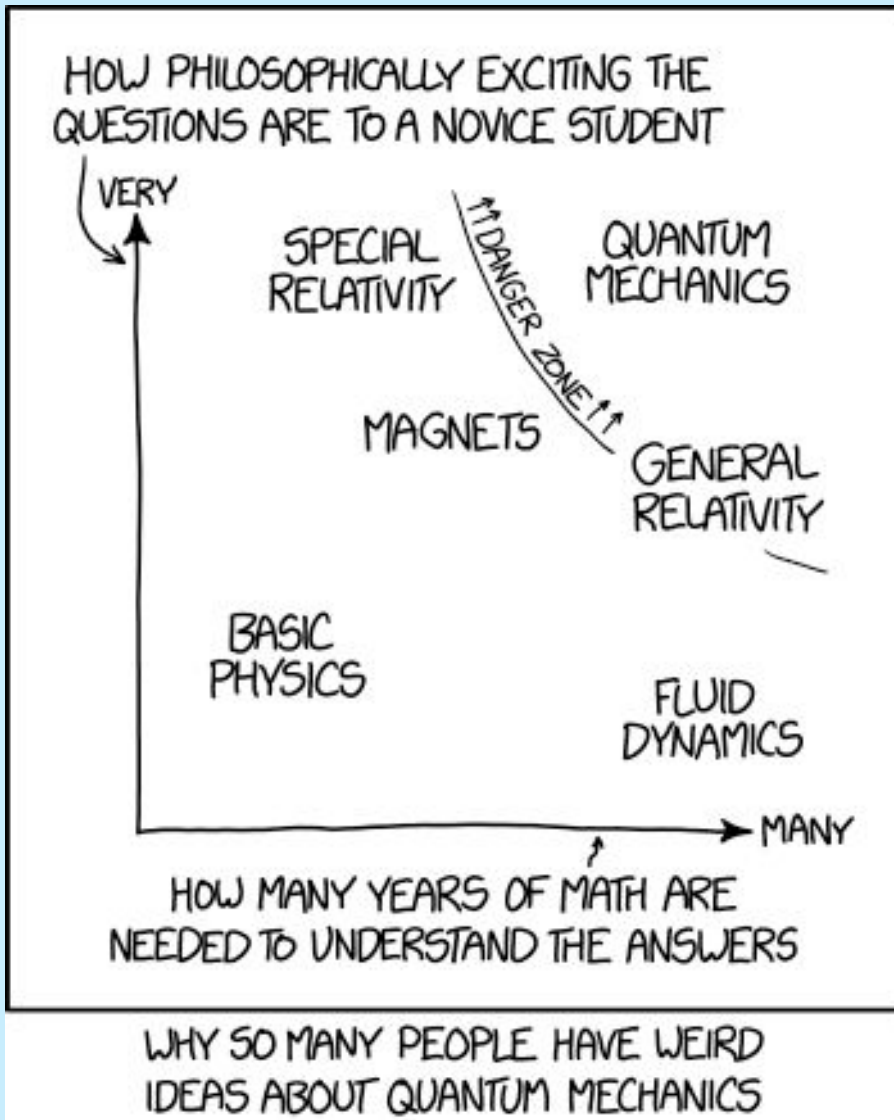
Dimensionless Numbers: In fluid mechanics, so-called dimensionless numbers are used to understand which of these terms are important, and which can be neglected:

$$Fr = \frac{v}{\sqrt{gl}}$$

$$Bo = \frac{\Delta \rho g l^2}{\sigma}$$

$$Ar = \frac{\rho \Delta \rho g l^3}{\mu^2}$$

FLUIDS AND YOU



Rain falls due to gravity, and drops are spherical due to surface tension



Water slides work because water flows downhill due to gravity



Removing gravity forces causes strange behavior in fluids!

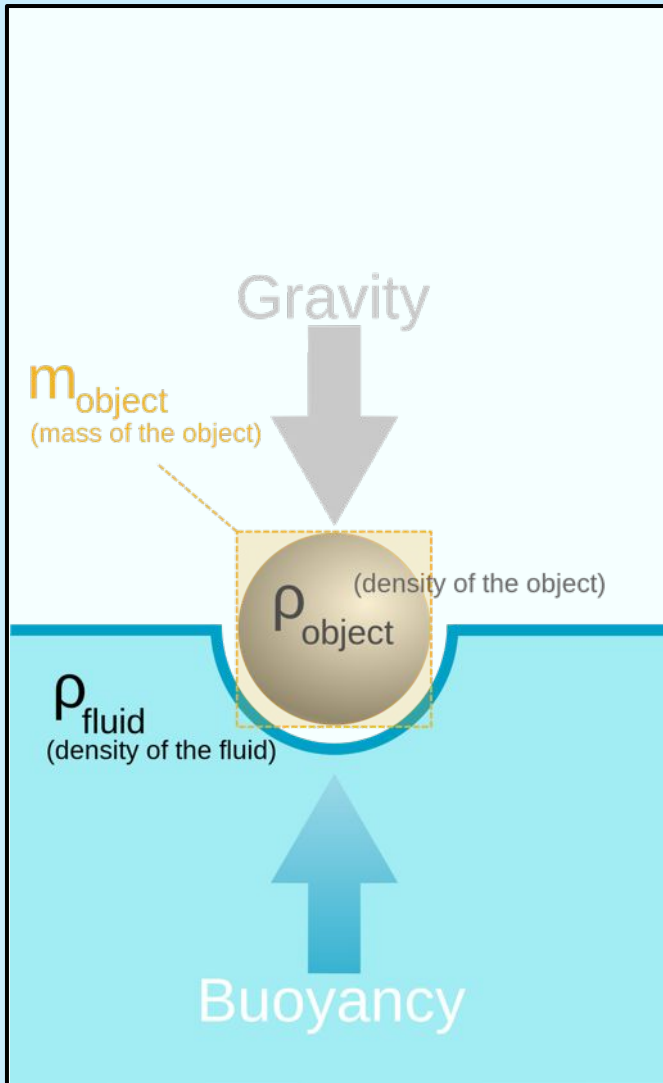
Effervescent tablets added to a floating drop of water on the ISS:

<https://youtu.be/qv5WCYeVxW4>

Drop of water with a bubble inside on a speaker on the ISS

<https://youtu.be/FTU2K5JVxUU?list=PL0MxE1LzKNjCdPDv0-04R6NjNWLqUFwJx>

BUOYANCY



Buoyancy: Objects denser (heavier) than a fluid sink, less dense (lighter) objects rise

What happens without gravity?

Air bubbles don't rise, and solid objects don't fall!

Studying buoyancy is important for research on colloidal mixtures, like lotion, paint, and more

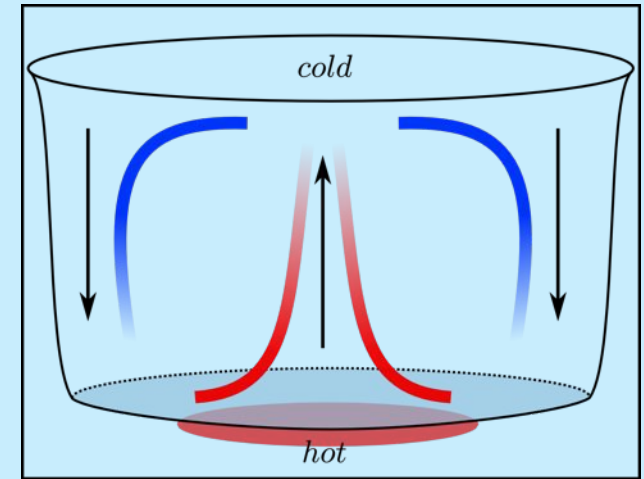


CONVECTION



Convection: Buoyant flows driven by temperature (or chemistry) gradients

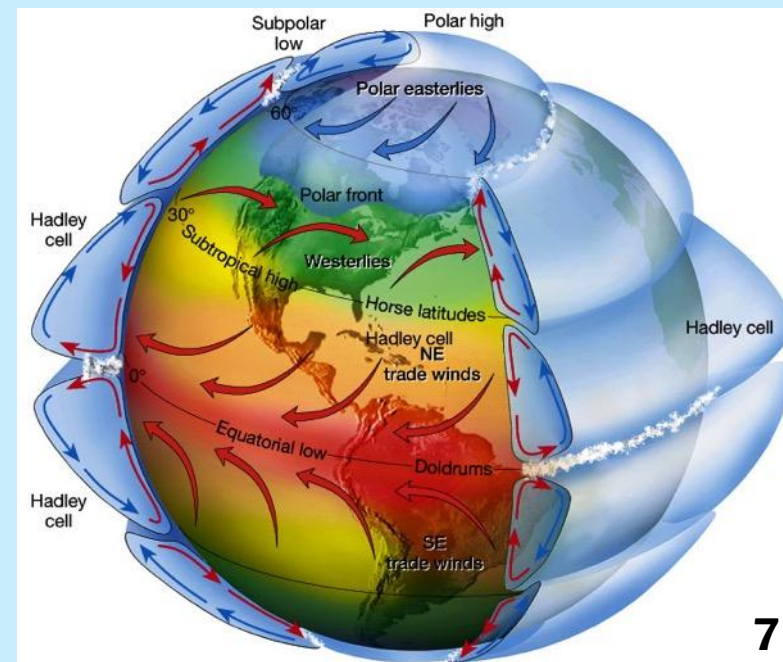
Known colloquially as “hot air rises”



What happens without

Buoyant convection is eliminated, meaning that heat transfer is very different!

But... a different type of convection caused by surface tension takes over

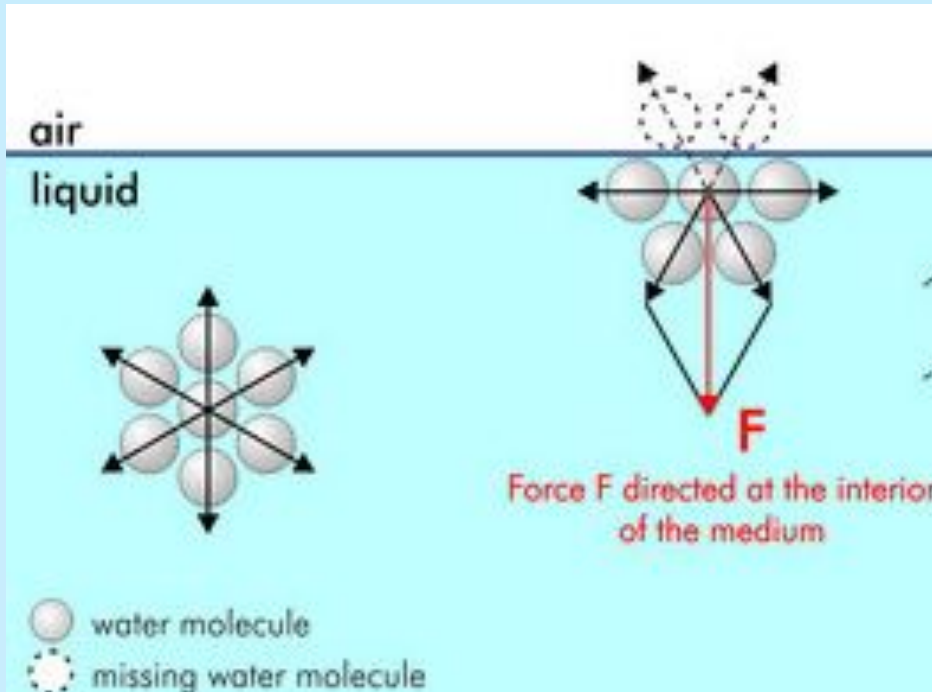


SURFACE TENSION



Surface Tension: Attraction of liquid molecules to each other

Marangoni Flows: Flow that occurs due to surface tension gradient



Quick Quiz: The size of a raindrop is found by the balance of surface tension and gravity:

$$Bo = \frac{\Delta\rho gl^2}{\sigma} = 1$$

$g = 9.81 \text{ m/s}^2$, $\sigma = 0.07 \text{ kg/s}^2$,
and $\Delta\rho = 998 \text{ kg/m}^3$.

What is the size of a drop, l ?

SUPERHYDROPHOBIC SURFACES



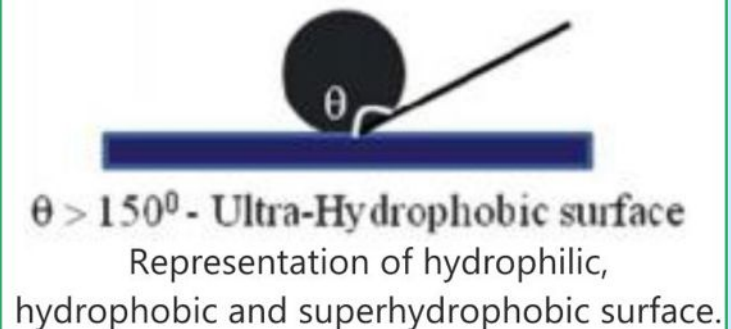
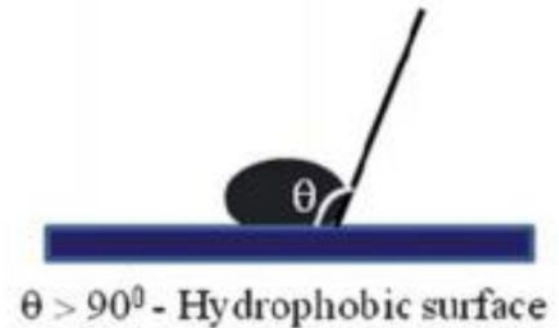
Hydrophobic: “Water-fearing”, aka, a property of an object that repels water

Hydrophilic: “Water-loving”, a property of attracting water

Superhydrophobic: Extreme hydrophobicity

Video: Hydrophobic paddles on the space station

https://youtu.be/TLbhrMCM4_0



REFERENCES AND RESOURCES



- Textbook: Physics of Fluids in Microgravity, by R. Monti. Earth Space Institute Book Series, 2001
- Document: NASA Researcher's guide to fluid physics on the space station. Access the pdf from:
https://www.nasa.gov/connect/ebooks/researchers_guide_fluid_physics_detail.html
- Additional fluids videos from Astronaut Don Petit:
<https://youtu.be/fWS0zWQ8DP4?list=PL0MxE1LzKNjCdPDv0-04R6NjNWLqUFwJx> ,
https://youtu.be/qHrBhgwq_Q?list=PL0MxE1LzKNjCdPDv0-04R6NjNWLqUFwJx ,
<https://youtu.be/CrTUpTDyGpl?list=PL0MxE1LzKNjCdPDv0-04R6NjNWLqUFwJx>