IMPACT: a strategic partnership for sustainable development in marine systems and robotics

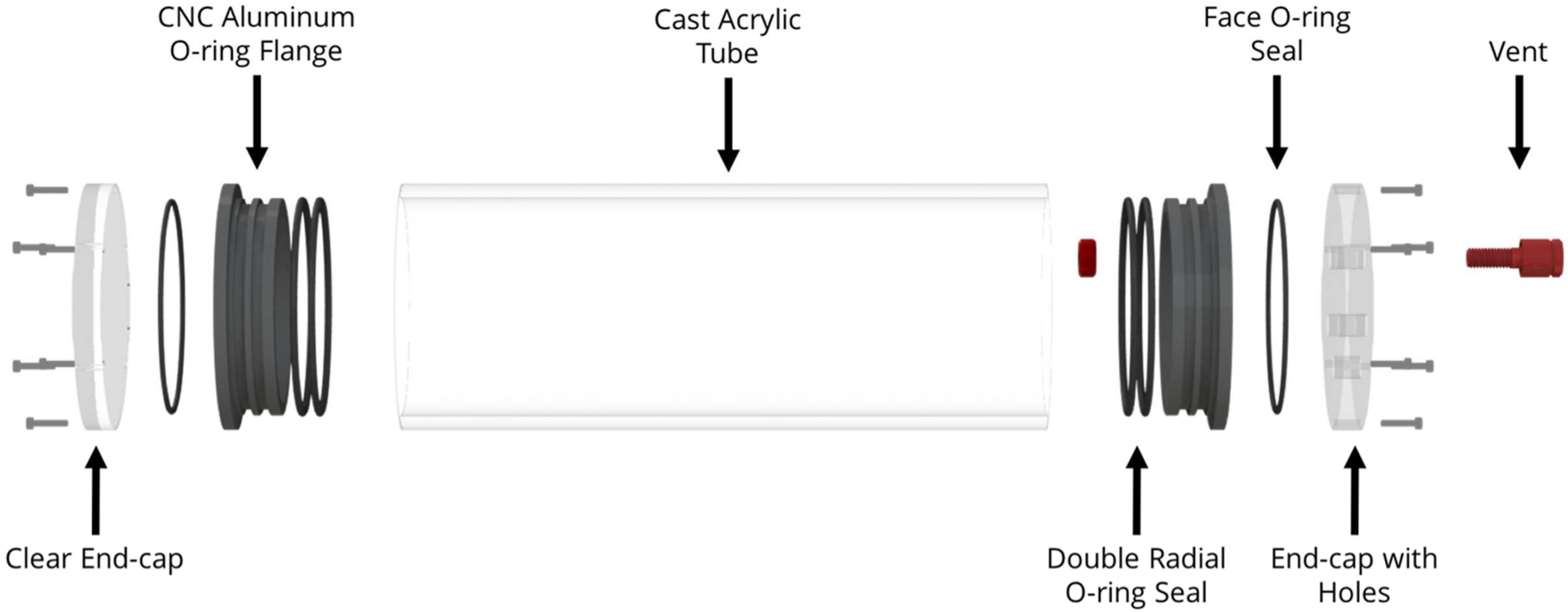
# Marine Systems & Robotics
# Unit 01 – Components

http://impact.uni-bremen.de/

# Components 1

Keeping things watertight and floating

# Example


CNC Aluminum
O-ring Flange
Cast Acrylic
Tube
Face O-ring
Seal
Vent
Clear End-cap
Double Radial
O-ring Seal
End-cap with
Holes

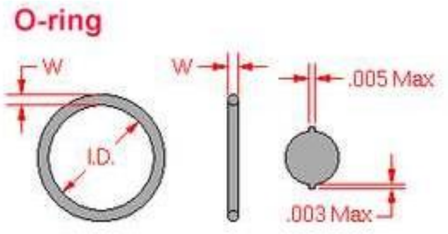
# Sealing: O-Rings

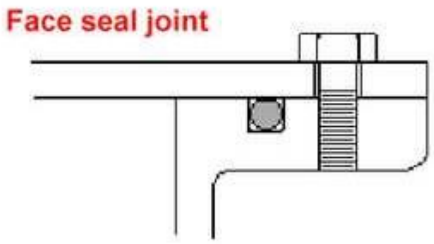
mechanical gasket

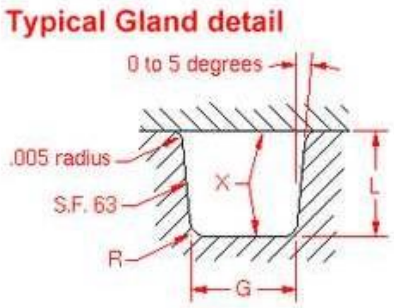
- in the shape of a torus
- made from an elastomer
- seated in a groove
- compressed during assembly
- creating a seal at the interface

metric O-rings

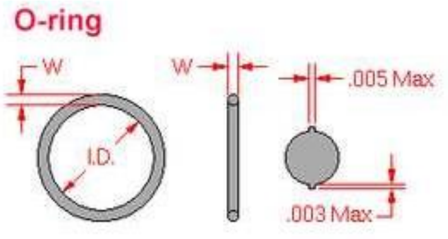
- inner dimension (mm) x cross section (mm)
- plus material, e.g.:
  - butadiene rubber (BR)
  - polychloroprene aka neoprene (CR), etc.



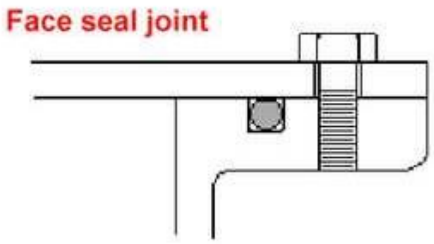



# Sealing: O-Rings




mechanical gasket
- in the shape of a torus
- made from an elastomer
- seated in a groove
- compressed during assembly
- creating a seal at the interface

***maintenance***
- needs regular ***cleaning*** and ***lubrication***
- typically with ***silicon grease***




metric O-rings
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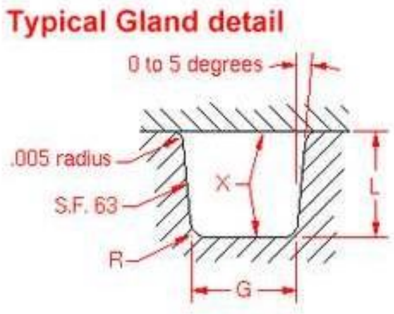


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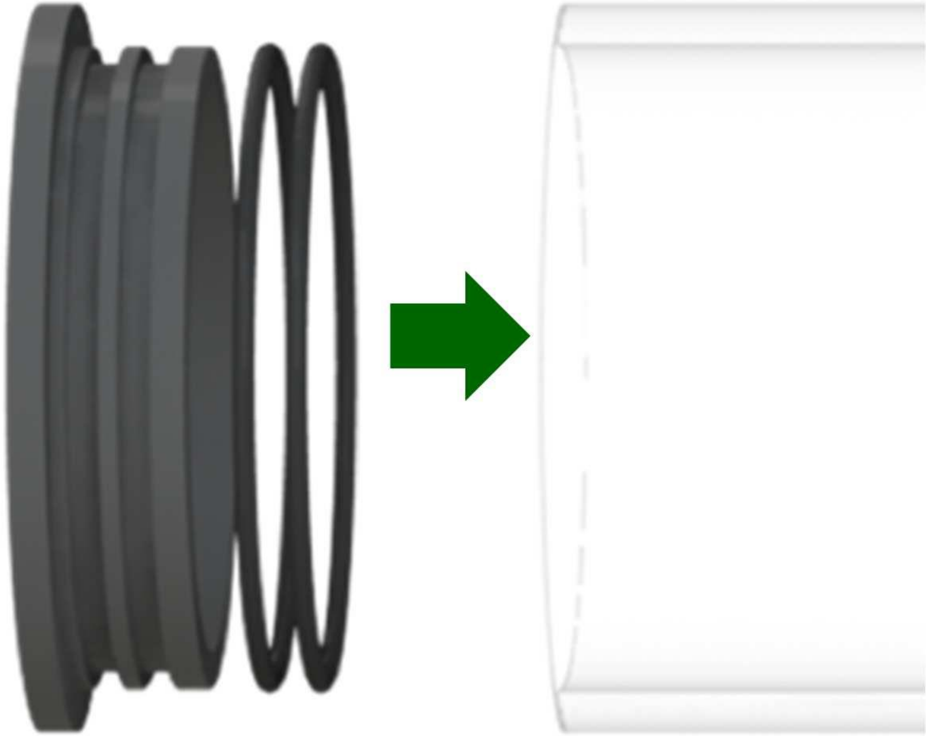
# Sealing: O-Rings

underwater bottles

end-caps often

- T-shape (“hat” shape)
- with double O-rings
- as radial seals
- on penetrating part

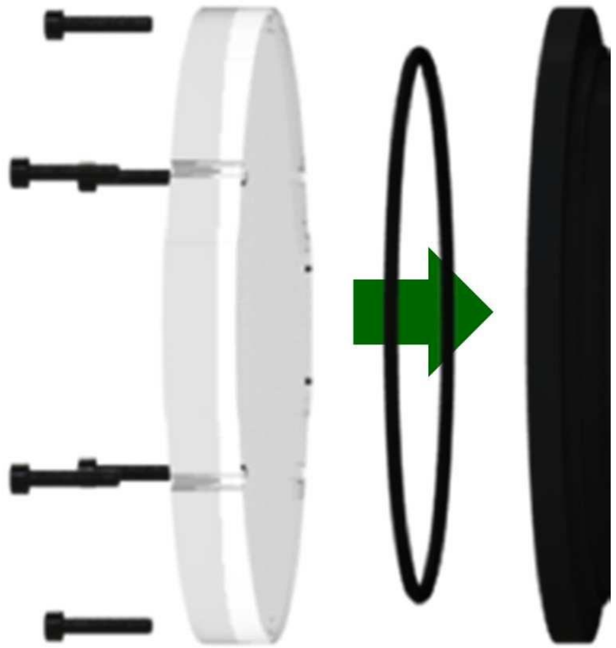


# Sealing: O-Rings

underwater bottles

end-caps sometimes

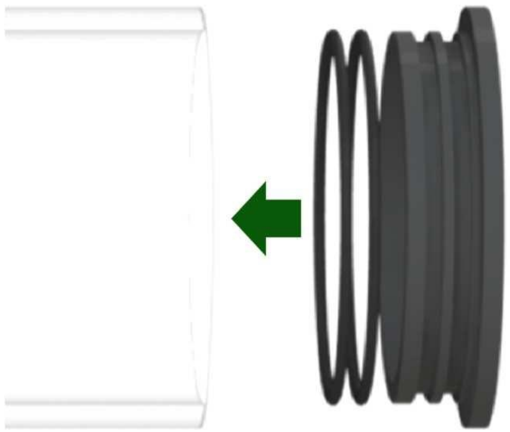
- flat disk shape
- with single (or rarely double)
- face O-ring

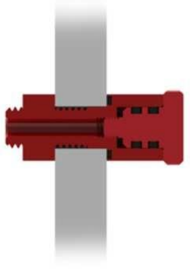


# Sealing: O-Rings

T-shape
- very water tight
- but pressing air out
- when pressing them in

⇒under-pressure in bottle
⇒end-cap(s) hard to remove
⇒use of a vent



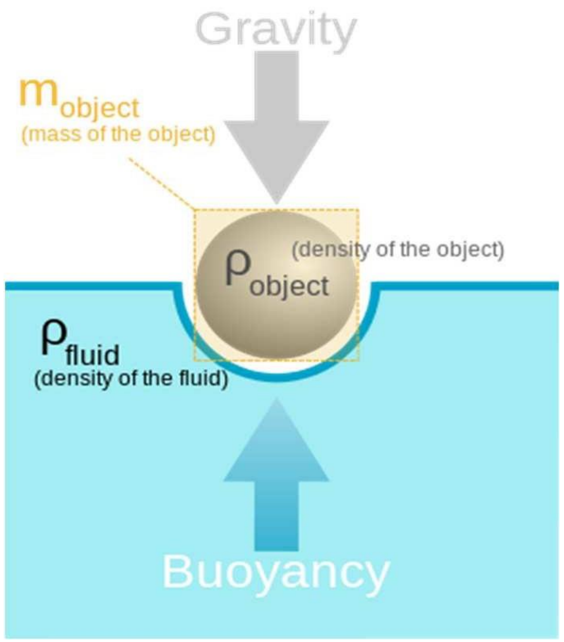


# Buoancy

- (upward) force B exerted by a fluid
- that opposes the weight of an immersed object

*Archimede's principle (212 BC)*

- *any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object*
- *i.e., buoyancy B equals weight of displaced fluid*

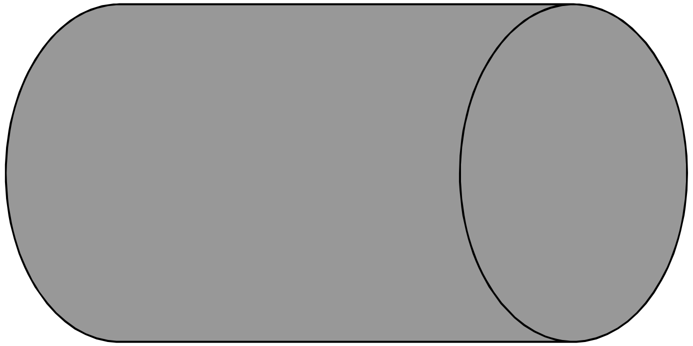



$$B = \rho V g$$

- *ρ: fluid density*
- *g: gravity*
- *V : volume*
  - *object vol. (fully submerged)*
  - *displaced fluid vol. (partially submerged)*

# Volume

- cylinder
  - radius r
  - length l
  - $V = pi\ r^2 * l$



- box
  - length l1
  - width l2
  - height l3
  - V = l1 * l2 * l3

# Water Density

not fix, especially influenced by

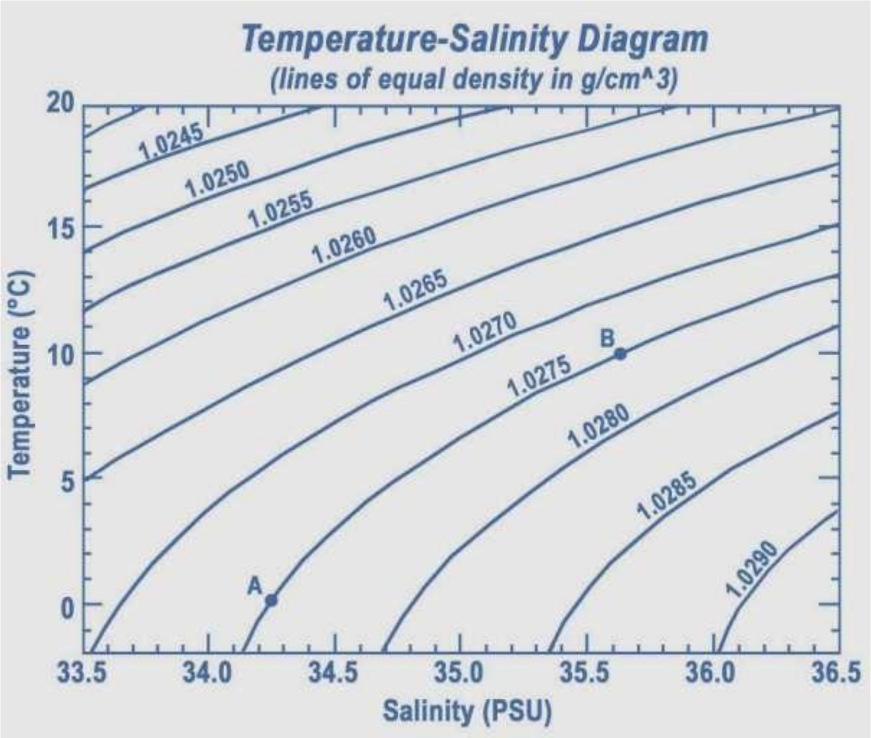
- salinity
- temperature

nominal values

- pure water: 1 kg/L (@4$^o$C)
- fresh water: ~1 kg/L

•salt water: 1.025 kg/L

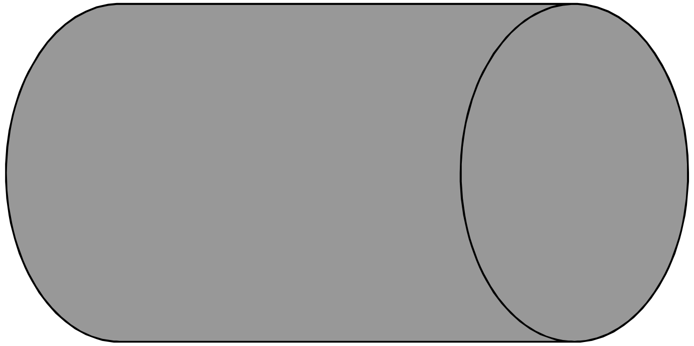
(note: 1 L = 1 dm$^3$)



# Example Buoancy

cylinder

- r = 10 cm
- l = 30 cm



$$V = \pi \cdot 100cm^2 \cdot 30cm$$
$$= \pi \cdot 0.01m^2 \cdot 0.3m$$
$$= 0.009425\,m^3$$

note: force *F, unit Newton [1N = 1 kg·m/sec²]*

# Example Buoancy

cylinder

- r = 10 cm
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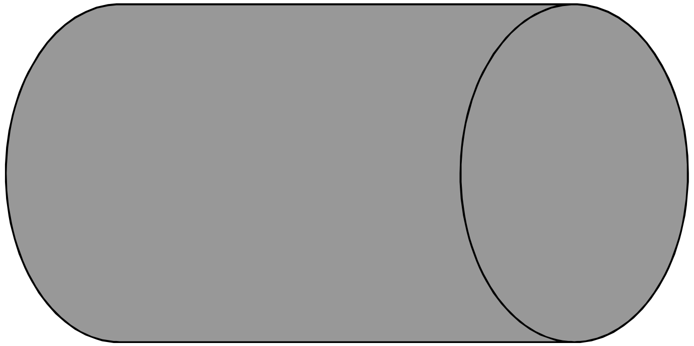

$$B = \rho V g$$

- *ρ: fluid density*
- *g: gravity*
- *V : volume*

$$V = \pi \cdot 100cm^2 \cdot 30cm$$
$$= \pi \cdot 0.01m^2 \cdot 0.3m$$
$$= 0.009425\,m^3$$

densities

- fresh water: ~1 kg/L
- salt water: 1.025 kg/L

(1 L = 1 $dm^3$ = 0.001$m^3$)

note: force *F, unit Newton [1N = 1 kg·m/sec²]*

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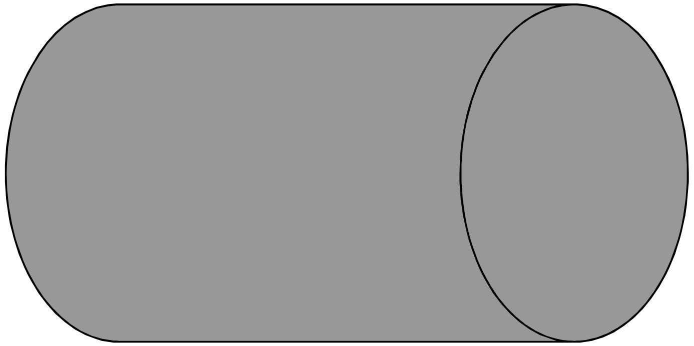
# Example Buoancy

- r = 10 cm
- l = 30 cm

$$V = 0.009425 m^3$$

gravity value

- g = ~9.8 m/sec²



$$B_{\text{fresh water}} = \rho_{\text{fresh water}} V g$$
$$= 1000\, kg/m^3 \cdot 0.009425 m^3 \cdot 9.8\, m/\text{sec}^2$$
$$= 92.365\, kg \cdot m/\text{sec}^2$$
$$= 92.365\, N$$

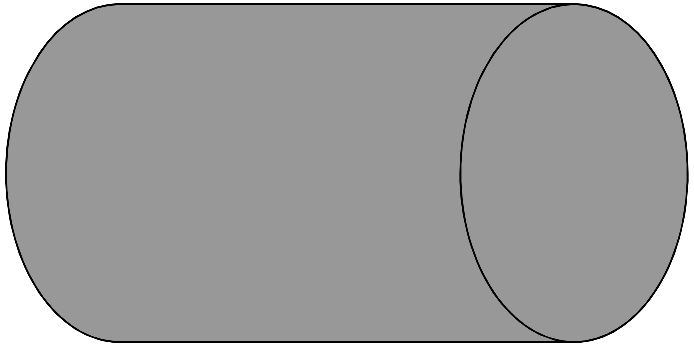
# Example Buoancy

- r = 10 cm
- l = 30 cm

$V = 0.009425 m^3$

gravity value

- g = ~9.8 m/sec²

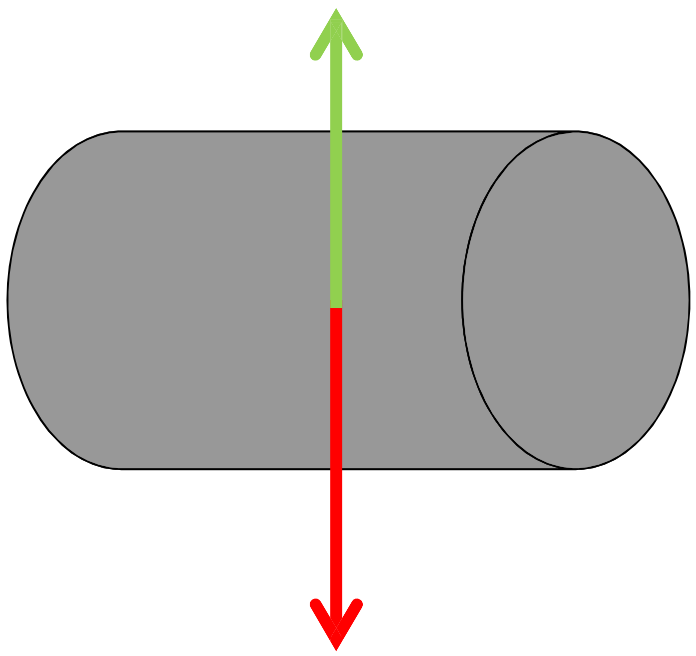


$$B_{\text{salt water}} = \rho_{\text{salt water}} V g$$
$$= 1025\, kg/m^3 \cdot 0.009425\, m^3 \cdot 9.8\, m/\sec^2$$
$$= 94.674125\, N$$

# Buoancy and Gravity

act in opposite directions

→ net buoyancy = buoyancy - gravity

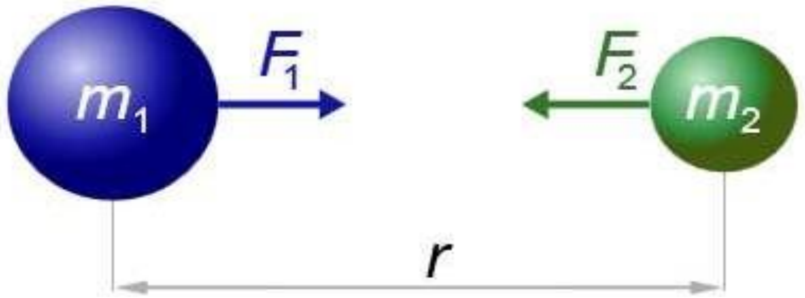


# Weight and Gravity

attractive force between two masses

- $m_1, m_2$ : masses [kg]
- G : gravitational constant [$6.67 \cdot 10^{-11}$ $m^3/(kg\ sec^2)$]
- r : distance between masses [m]

$$F = G \frac{m_1 m_2}{r^2}$$



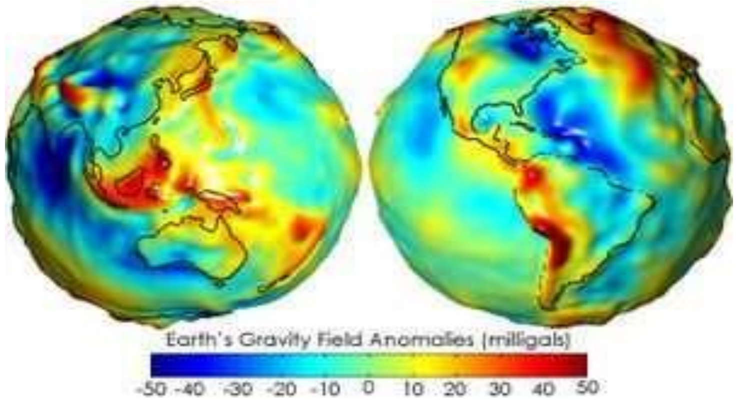
# Weight and Gravity

special case: on the surface of earth

- $F_g$: gravitation force (on earth) [N]
- m: mass [kg]
- g: (standard) gravity value [9.8 m/sec$^2$]

*very reasonable, but nevertheless approximation*

$$F_g = mg$$



# Buoancy and Gravity

act in opposite directions

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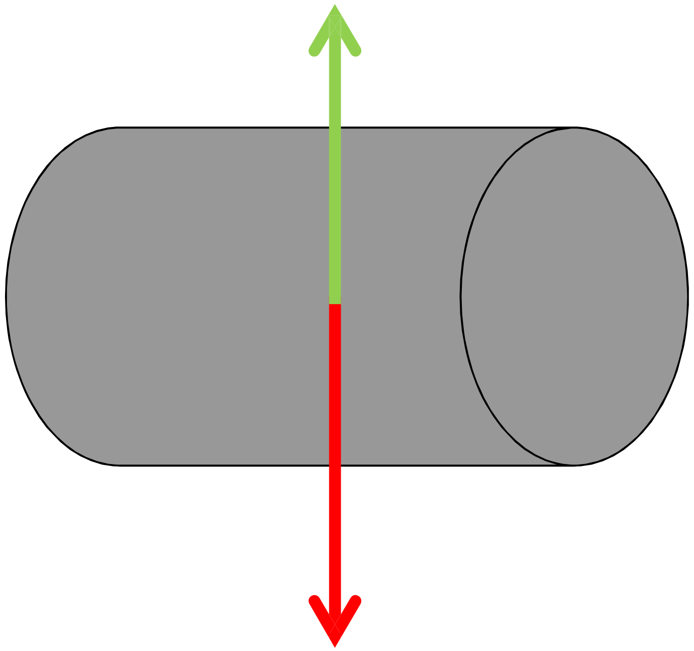
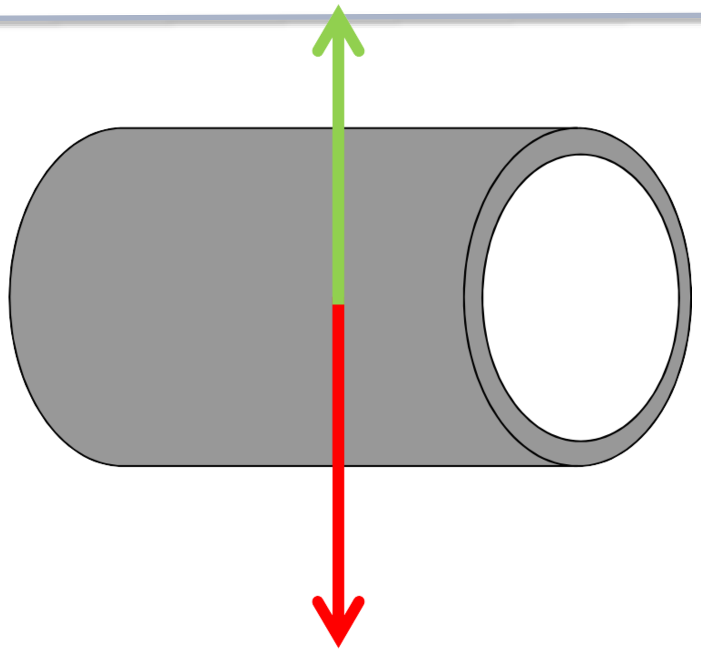


Net buoyancy aluminum tube?
(density alu ~2.7 t/m3)

# Buoancy and Gravity

weight aluminum tube

- density alu: ~2.7 $t/m^3$
- volume: outer – inner cylinder
  - density air: ~1.23 $kg/m^3$
  - i.e., 3 orders of magnitude less than alu
  - weight of the inner cylinder is negligible



e.g., tube with

- $r_{out}$ = 10 cm
- $r_{in}$ = 8 cm
- l = 30 cm

$$V = \pi \cdot r_{out}^2 \cdot l - \pi \cdot r_{in}^2 \cdot l = \pi \cdot (r_{out}^2 - r_{in}^2) \cdot l$$

$$= \pi \cdot (0.01 m^2 - 0.0064 m^2) \cdot 0.3 m$$

$$= 0.003393 m^3$$

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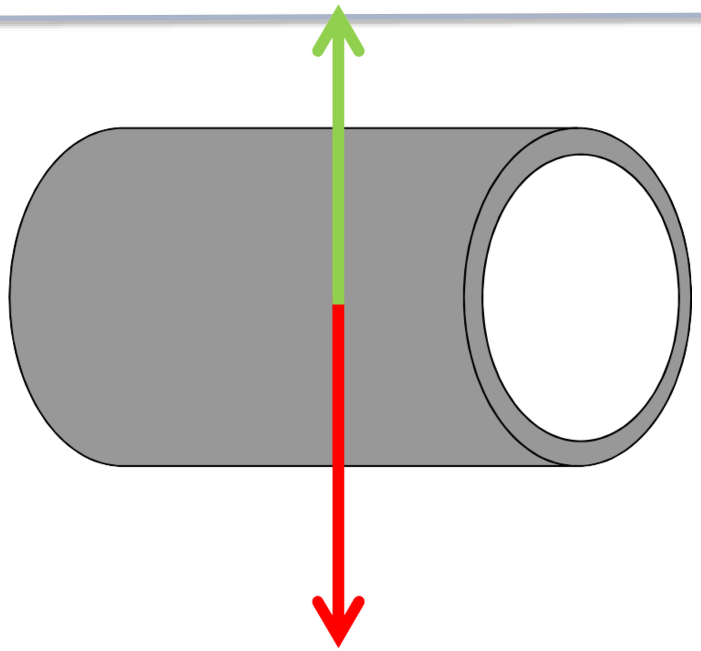
# Buoancy and Gravity

e.g., aluminum tube

- $r_{out}$ = 10 cm
- $r_{in}$ = 8 cm
- l = 30 cm
- density alu: ~2.7 $t/m^3$



$$F_g = mg = \rho V g$$

$$= 2700\ kg/m^3 \cdot 0.003393\ m^3 \cdot 9.8\ m/\sec^2$$

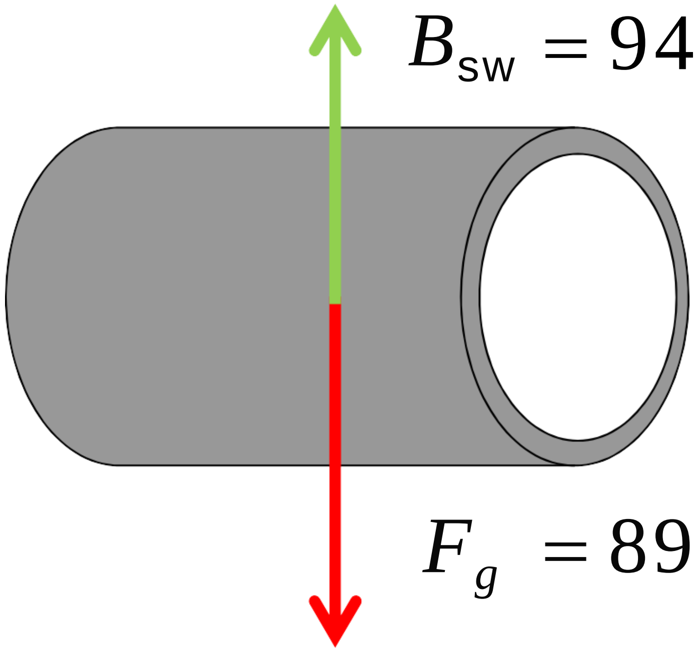
$$= 89.7767\ N$$

# Buoancy and Gravity

e.g., aluminum tube

- $r_{out} = 10$ cm
- $r_{in} = 8$ cm
- l = 30 cm
- density alu: ~2.7 t/m³

$$B_{sw} = 94.674125\,N$$



$$F_g = 89.7767\,N$$

→ “floating up”

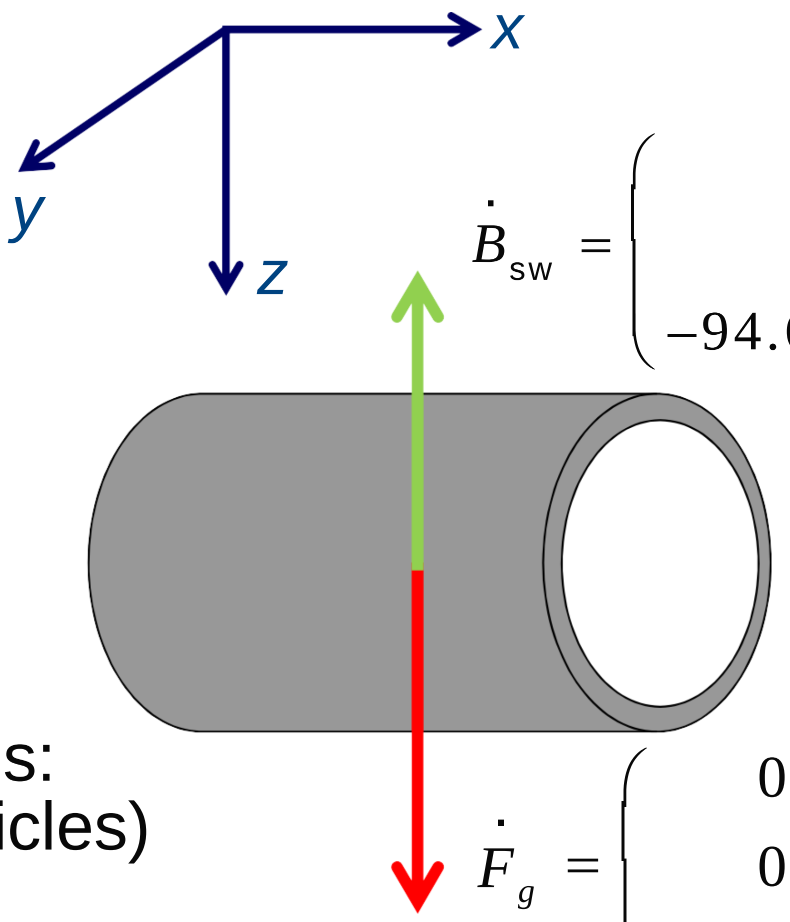
# Buoancy and Gravity

more precisely

- buoyancy and gravity
- are forces, i.e., vectors
- so far: only magnitude

reference frame

- right-handed
- convention for flying bodies: (including underwater vehicles) z-axis pointing down




$$\dot{B}_{sw} = \begin{pmatrix} 0 \\ 0 \\ -94.674125 \end{pmatrix} N$$

$$\dot{F}_g = \begin{pmatrix} 0 \\ 0 \\ 89.7767 \end{pmatrix} N$$

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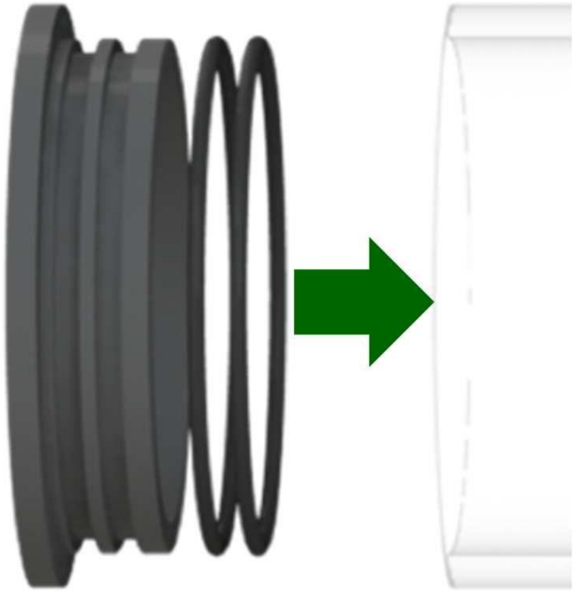
# Buoancy and Gravity

same analysis for all components

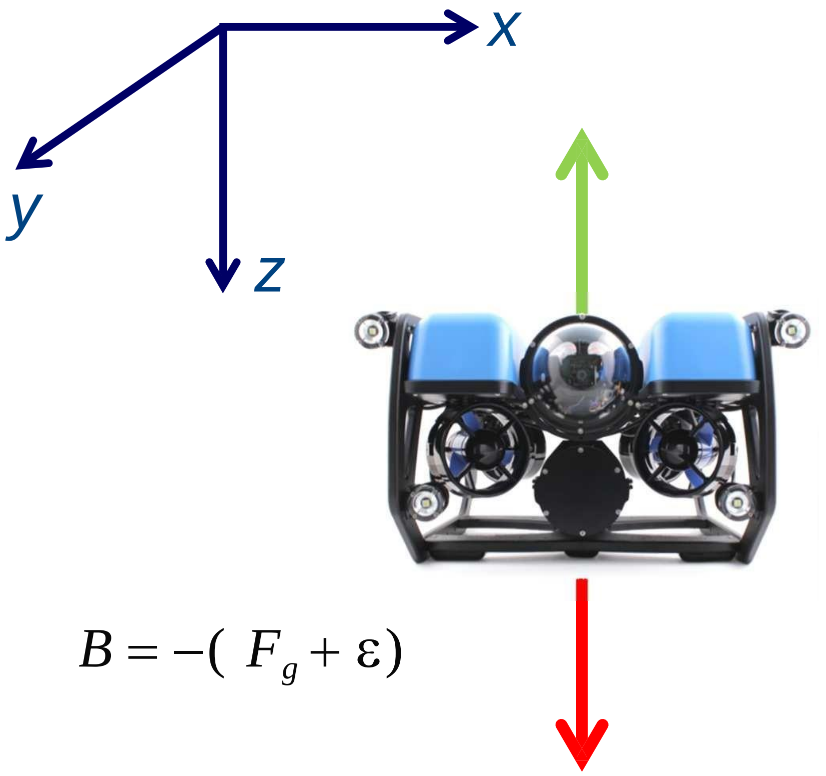
- some only contribute to weight
  - e.g., everything inside bottles
  - batteries, computer, ...
- some mixed
  - e.g., T-shape end-caps
  - partially exposed to water (buoyancy + weight)
  - partially inside bottle (only weight)



# Buoancy and Gravity

the overall vehicle should be

- neutrally buoyant,
  - only small vertical force needed
  - to dive up and down
- respectively slightly positive
  - if no force (e.g., thruster failure)
  - then slowly surfacing



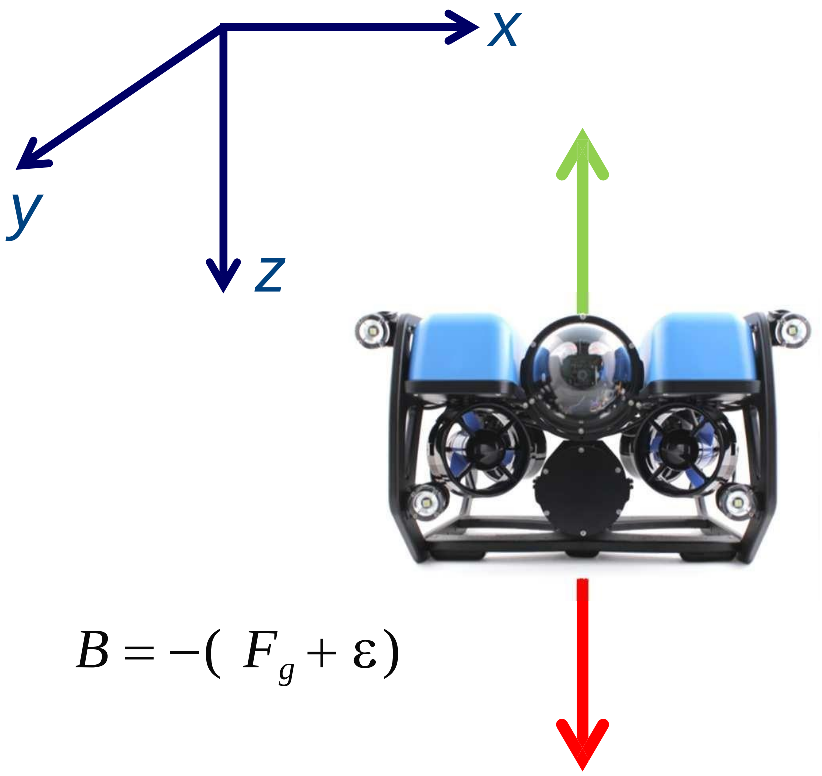

$$B = -(F_g + \varepsilon)$$

# Buoyancy and Gravity

trimming:

neutral (slightly positive) buoyancy

- if "too heavy"
  - then increase net buoyancy
  - with floatation foam
  - incompressible (up to a certain depth)
  - while having low density
- if "too light"
  - then add trimming weights
  - typically, lead weights
  - also needed to adjust to different water densities (fresh or salt)




$$B = -(F_g + \varepsilon)$$

# Components 2

Electrical Power

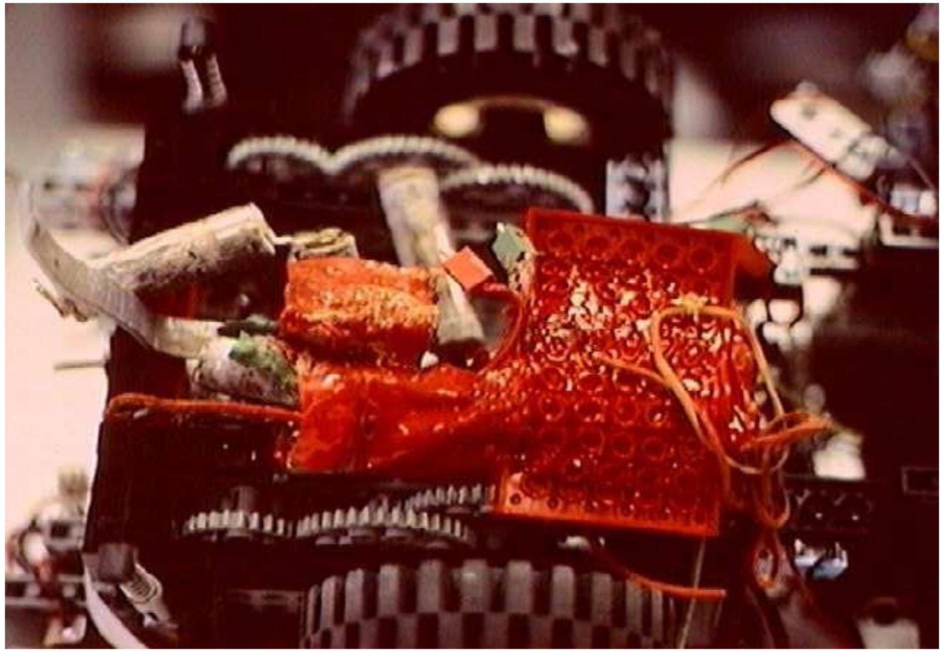
# Components 2

- primary = one way usage
- secondary = re-chargeable

common types (secondary)
- lead-acid
- NiCad (Nickel-Cadmium)
- NiMH (Nickel-Metal-Hydride)
- Li-Ion / LiPo (Lithium-Ion / Lithium-Polymer)

# General Properties

- capacity: max. energy
- density: capacity/weight
- voltage changes with state of charge
- internal resistance: determines max. power
- re-charging is **dangerous**



| | Lithium | Alkaline | NiCad | NiMH | lead-acid | LiIon |
|---|---|---|---|---|---|---|
| class | primary | | secondary | | | |
| energy-density (Wh/kg) | 300 | 140 | 39 | 57 | 35 - 44 | 85 - 120 |
| capacity (Ah) | 1.8 - 14 | 1.4 - 10 | 0.5 - 4.0 | 1.1 - 2.3 | 1.0 - 80.0 | |
| cell voltage (V) | 1.5 | 1.5 | 1.2 | 1.2 | 1.2 | 3.6 |
| battery voltage (V) | 1.5 / 9 | 1.5 / 9 | 1.2 | 1.2 | 6 / 12 | 3.6 / 7.2 |

# LEAD-ACID

- high capacities / medium energy density
  - car / motorcycle: ~ 35Wh/kg
  - special purpose (UPS): ~45Wh/kg
- typical rated voltage: 12V (car), but also 6/24/48V
  - cell voltage: 2V, but serial housing
- rather easy to handle, but
  - restrain current (water electrolyze => hydrogen)
  - rapid self-discharge
  - total discharge can destroy the battery
  - bad performance at low temperatures

# NICAD, NIMH

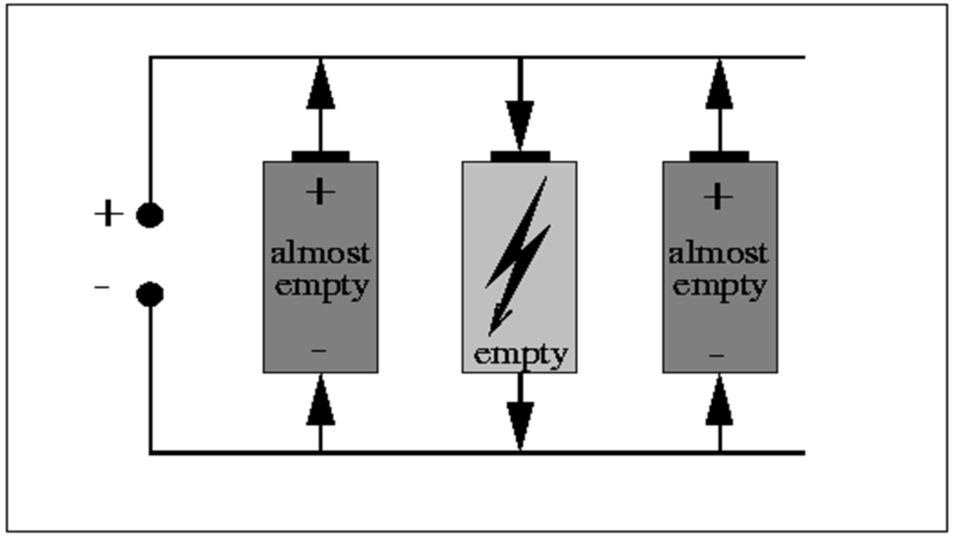
- used to be most common for small / medium capacity
- similar behavior, though NiCad “low-grade”
  - memory-effect
  - environmental problems
  - but cheaper
- available in battery sizes from “small” to “large”
  - also in typical consumer packages (A, AA, AAA, D, etc.)
- rated cell voltage: 1.2V

# Li-ION / LiPo

- meanwhile **very popular**
  - cellular phones, video-cameras, laptops, etc.
- very high energy-density
- rated cell voltage: 3.6V
- difficult to handle
  - dis- and re-charge needs special control
  - voltage and current regulation needed
  - dangerous: risk of fire when over-charged or short-cut (lithium fire & water => explosion)

# Battery Packs

- cells always in series
- never in parallel
- all cells should be “the same”
  - chemistry, rating, type, manufacturer, etc.
  - do not exchange single cells
- heat sensitive
  - careful soldering



# Battery Packs

Important decision: arrangement

- 1x pack for everything?
- or 2x packs
  - split supply for motors (can generate noise signals)
  - and for computer & sensors (sensitive to noise)
  - plus allows different voltages & amounts of energy

# Battery Packs

- battery holder
  - seems convenient but
  - only low currents
  - and risk of loose connections

- soldering tags
  - high currents (~10-20 A)
  - robust connections

# Battery Packs

- e.g., D-size NiMH cells
  - aka Mono, R20, UM1, LR20, AM1
  - very wide availability
  - typical capacity: 10 Ah


- 12V configuration
  - i.e., 10 cells
  - in popular 5N2PL set-up (5 cells vertical in 2 parallel set-ups
  - ca. 10 Ah => 120 Wh
  - ca. 1.7 kg
  - ca. 163 mm x 62 mm x 66 mm (L x H x W)

# Batteries as Power Suppliers

- battery voltage is not fix, i.e., unregulated supply
- many devices (computers, sensors, etc.) need fixed input
- usually multiple different voltages in one system

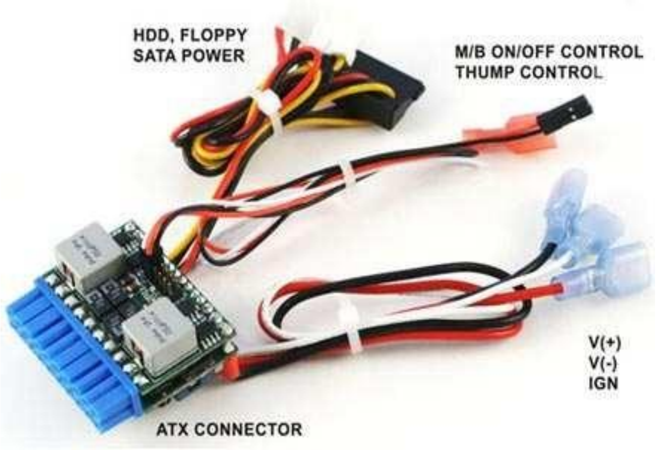
regulated voltage supplies

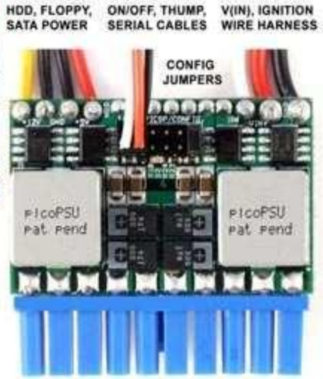
- aka DC/DC converters
- fixed, controlled voltage output
- often wide input range
- switching supplies are most efficient
- max. current, i.e., max. W important


# Batteries as Power Suppliers

regulated voltage supplies

- special case PC supply
- many voltages & high W
- specialized solutions exist
- aka embedded supplies
- max. W very important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# Components 3

Thrusters

# Newton’s laws

**1st Law:** An object at rest will stay at rest, and an object in motion will stay in motion at constant velocity, unless acted upon by an unbalanced force.

**2nd Law:** Force equals mass times acceleration.

**3rd Law:** For every action there is an equal and opposite reaction.

# Newton's laws

1. $\sum F = 0 \Leftrightarrow V = A = 0$

2. $F = ma$

3. $F_a = -F_r$

- F: force [N = kg·m/sec$^2$]
- v: velocity [m/sec]
- a: acceleration [m/sec$^2$]
- m: mass [kg]
- $F_{a/r}$ : action/reaction force

# Inertia

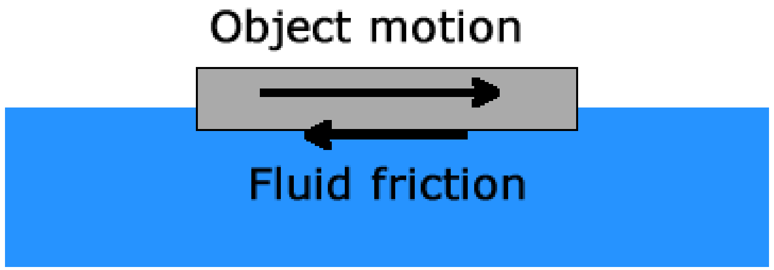
Inertia is the tendency of an object to **resist** changes in its velocity: whether in motion or motionless

These pumpkins will not move unless acted on by an unbalanced force.

# Inertia

Why then, do we observe every day objects in motion slowing down and becoming motionless seemingly without an outside force?

It's a force we sometimes cannot see – **friction**.

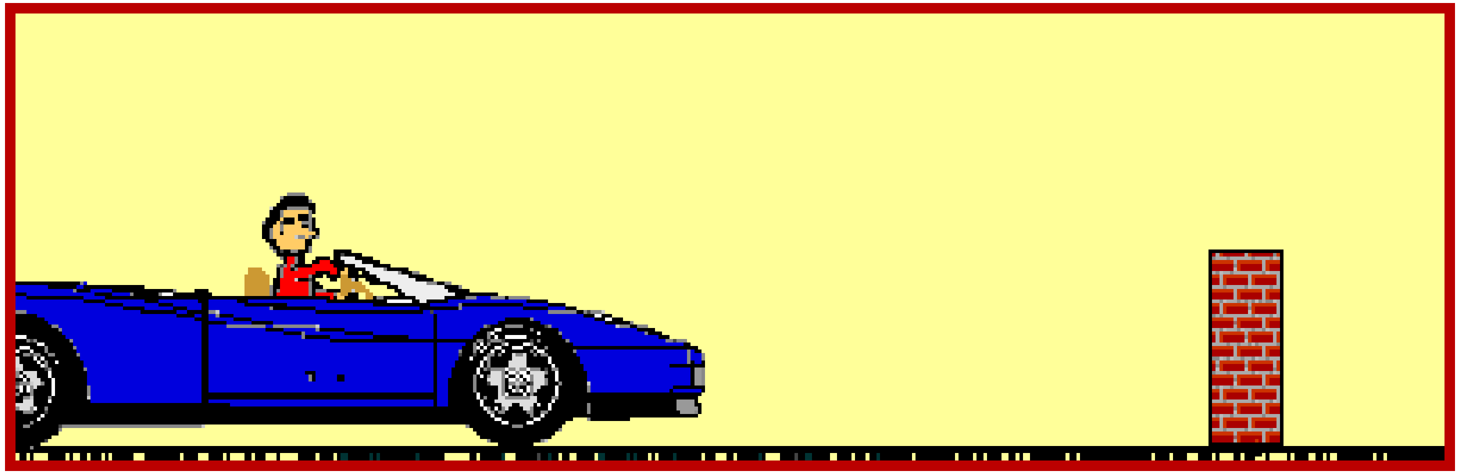


# Inertia

Because of inertia, objects (including you) resist changes in their motion.

When the car going 80 km/hour is stopped by the brick wall, your body keeps moving at 80 km/hour.

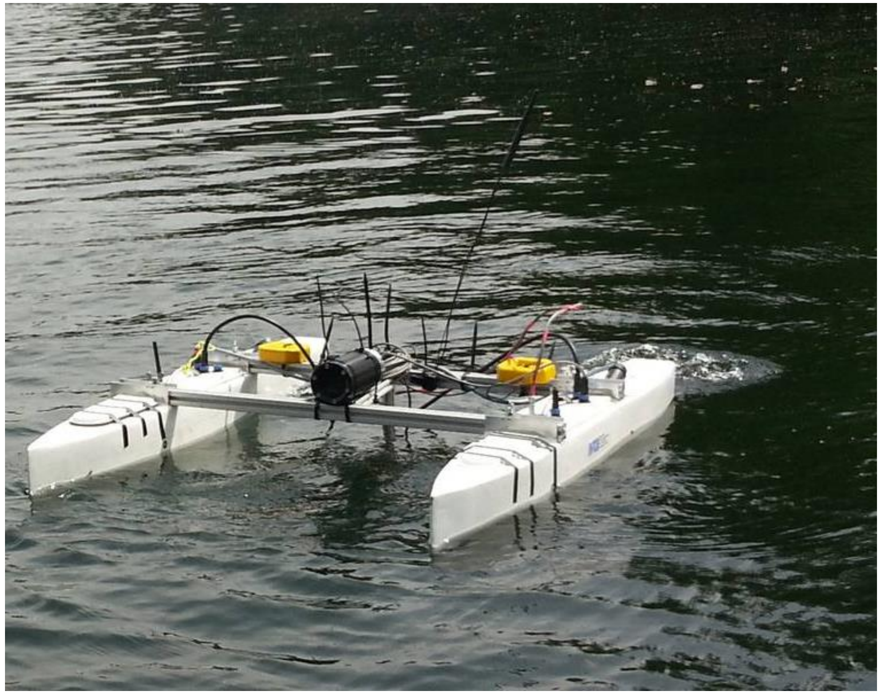
→ **Wear a seatbelt!**



# Inertia

Even when motors are off,

ASV / AUV may keep moving!!!



# Thrust

reaction force T when system expels mass

- generates force in opposite direction of accelerated mass
- follows from Newton #1 and #2
- used a.o. for aerial & marine (propeller that move air/water)

$$T = v \cdot dm/dt$$

- v : (exhaust) velocity
- dm/dt : rate at which mass is expelled (aka mass flow)

# Thrust

aerial & marine propeller

$$
\begin{aligned}
T &= v \cdot dm/dt \\
&= v \cdot \rho A v \\
&= \rho A \cdot v^2
\end{aligned}
$$

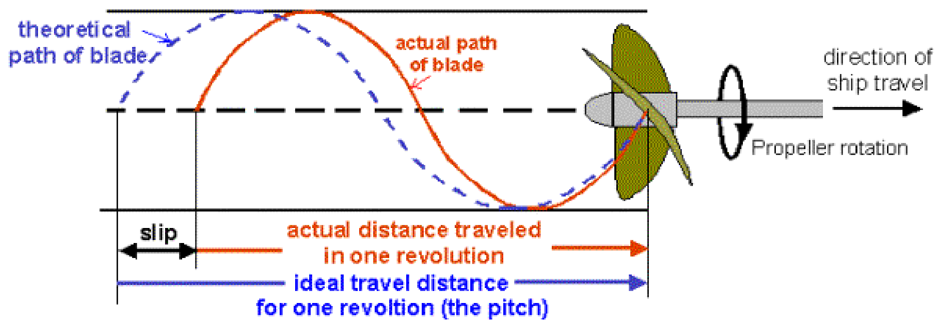
- ρ : fluid density [kg/m³] (see also drag)
- A : cross-section of propelled volume V

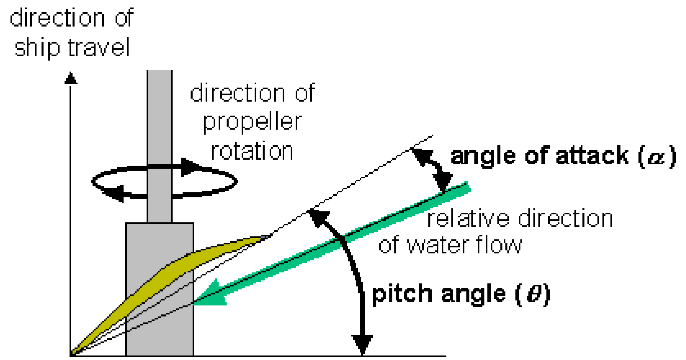
# Thrust

aerial & marine propeller $T = \rho A \cdot v^2$

*V*, resp. *A* follow from propeller design

- including losses, etc.
- often treated as constants found through calibration
- or approximated by the sweep area
  (plus calibration of motor+prop system)



# Thrust

propellers

- often not symmetric w.r.t. +/-ω
- i.e., „stronger“ in one rotational direction, hence handedness:
- normal n pointing along motor to propeller axis, thrust vector t
  - right handed: $\omega>0$ (CCR) => $t = c\omega^2\, n$ , $\omega<0$ (CR) => $t = \eta\, c\omega^2\, -n$
  - left handed: $\omega<0$ (CR) => $t = c\omega^2\, -n$ , $\omega>0$ (CCR) => $t = \eta\, c\omega^2\, n$
  - with scaling factor $\eta < 1$

# QUESTIONS ?