# Welcome to Phys 2C. Fluids, Waves, Optics, and Thermodynamics.

Prof: Ken Intriligator

http://keni.ucsd.edu/f14

and on TED

# The team:

- Ken Intriligator ("Ken", or "coach"). (My research: quantum field theory and string theory. Everything, electrons, photons, quarks etc, are ripples of quantum fields, which fill all spacetime. Feel free to ask me (or the TAs) about it!)
- TAs: Miles and Noam, top grad students.
- Classmates. Buddies. (Not on exams!)
- You! Goal: exercise your brain. Learn.

# Grades assigned by a computer

See syllabus for its mathematical formula.

# FAQ:

- Clickers? No.
- Online homework? No.
- Class attendance checked? No.
- Calculators on exams? No.
- Bring "cheat sheets" to exams? Yes. 3x5 cards for quizzes, and full page for final.

# Young and Freedman

- “University Physics”. **Best** book for Phys 2 series, IMHO. Widely regarded as the most advanced 2 series option. It’s chock full of non-trivial exercises. Some profs fear it’s too hard for the students. Is it? I think not! You’re UCSD - the smart ones! :-)
- You can actually use any book you like. Many options. Completely up to you. But I strongly recommend using our textbook.

# Class schedule

- Monday, Tuesday night, and Wednesday lectures. Overview the week's chapter, work examples.
- Tuesday, Wednesday and Thursday night (late, ugh!) discussion and problem sessions with TA. Optional
- Fridays: quiz, next 8 weeks. Drop 2.

# Schedule / advice

- Sunday: read through all the recommended exercises for upcoming week. Appetizer for your brain. Mull a bit before you calculate!
- Monday: skim book chapter before lecture.
- Tues - Thurs: solve the exercises. Do it yourself, or it's not really exercise!
- Friday: review, make eqn. sheet, take quiz.
- Saturday: take a break (if you want to)!

# Why no calculators?

- The math will be trivial. E.g. $\pi \approx e \approx \sqrt{10} \approx 3$
- Focus on conceptual points, and **human** thinking skills. (Vs. Robot-think, avoid it!)
- Everyone spends enough time on their devices, it's important to not be overly dependent on them. Will help your future employability if you can solve problems that computer's can't. Like captcha!

# Quiz advice

- Read through each question, and think a moment before you calculate anything.
- No complicated calculations should be needed. If you find yourself doing one, it's a warning sign that you're probably on the wrong track. Japanese food packaging analogy: always one easy way to open it - trying it the wrong way can be impossible. If you need to, move on to another question, and come back to it at the end.

# Sample quiz question

- A pendulum consists of a light rope and a solid gold ball. It has a period of 1 second. (a) What would be the period if the ball is replaced with a silver one of the same size? (b) What about if the rope is replaced with a rope of four times the original length? (c) What about the original pendulum, but on planet X, where everything weighs 9 times its weight on Earth?

# Dimensional Analysis

- An easy way to solve many problems!!!!
- 3 basic quantities with units: length, mass and time. In metric, e.g. MKS.
- Everything with units is built from them.
- Learning how to use this will pay off, on our quizzes and later. It is super important.

# Pendulum, by D.A.

- Pendulum bob's mass = M. Rope (negligible mass) has length L. Restoring force due to gravity, so the period will also depend on g.
- Units of g = accel: [g]= length/time^2.
- Period: $T \sim \sqrt{(L/g)}$ Note: M can't enter!
- Can now immediately solve the sample questions!

# Pendulum by DA, cont.

- Original pendulum has M=?, L=?, T=1 sec.
- Part (a): replace M with M' (also =?).
- Part (b): replace L with L'=4 L.
- Part (c): change g to g'=9g. (W'=mg'=9W.)
- Just use $T \sim \sqrt{(L/g)}$ Immediately gives:
- (a) T'=1 sec, (b) T'=2 sec, (c) T'=1/3 sec.

# DA: use M, L, T for all

$$[Force] = [ma] = ML/T^2$$

$$1N = 1kg\ m/s^2$$

$$[Energy] = [mv^2] = ML^2/T^2$$

$$1J = 1kg\ m^2/s^2$$

$$[Power] = [E/T] = ML^2/T^3$$

$$1W = 1kg\ m^2/s^3$$

$$[Pressure] = [F/A] = M/T^2L$$

$$1Pa = 1N/m^2 = 1kg/s^2\ m$$

$$[Temp.] = [E/k_B] = ML^2/T^2k_B$$

We'll discuss Temp more soon.

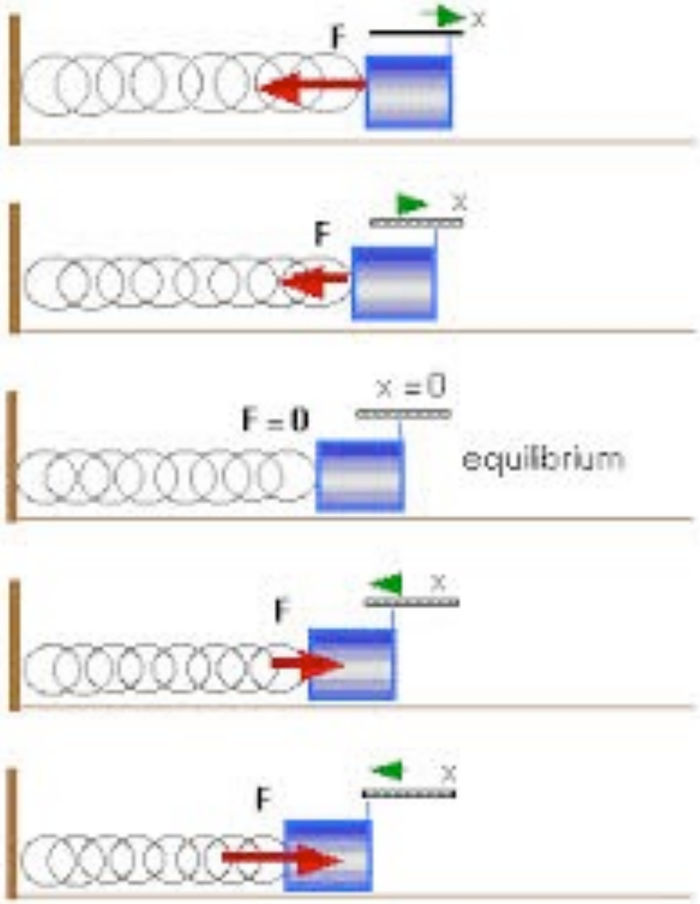
# Appetizer: Review SHO

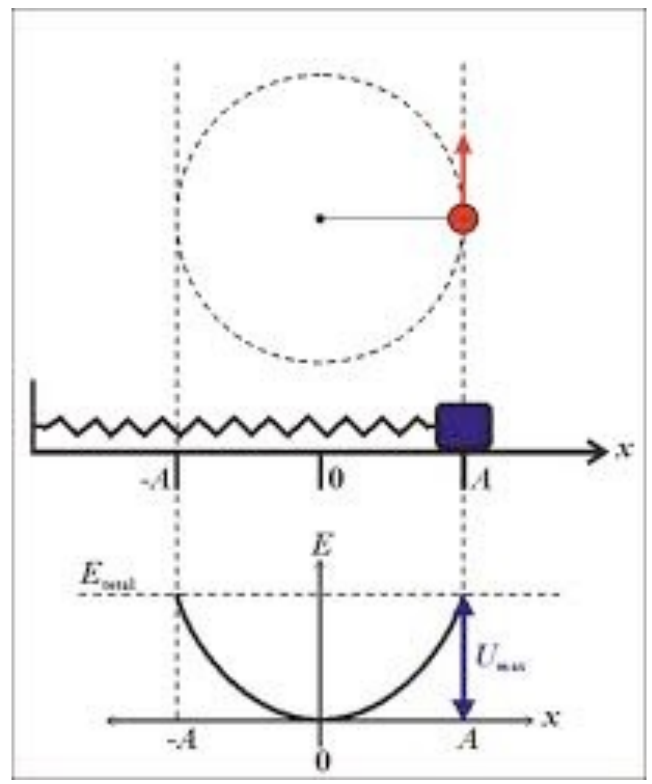
- Simple setup, applies all over the place in Nature. Whenever small displacement from equilibrium. Ignore friction here. Consider motion in 1d, along x axis. Let x=0 be the equilibrium position. Force F(x) with F(0)=0. For small x, can always Taylor expand F(x) and keep just the first term:

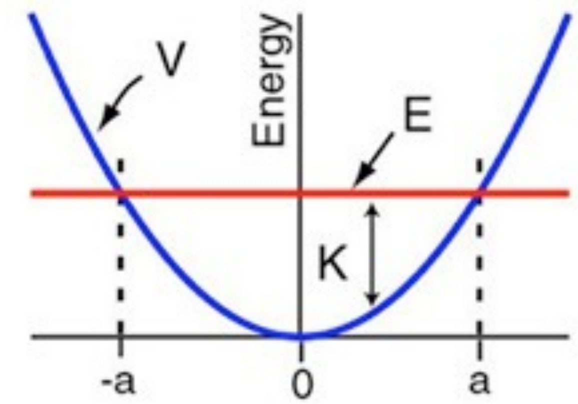
$$F(x) \approx -kx$$

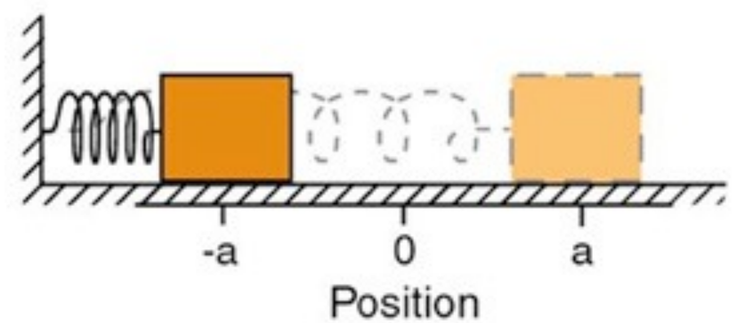
$$[k] = [F/L] = [M/T^2]$$

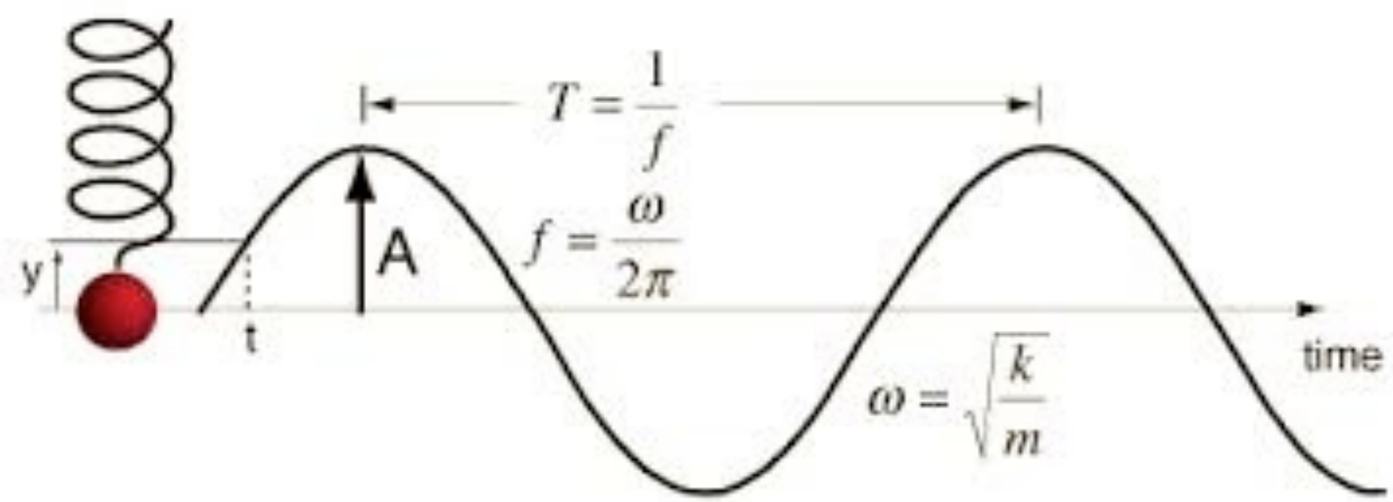
# Physics of the SHO



# Now the math:

key: - sign for oscillations

$$m\frac{d^2x}{dt^2} = -kx \rightarrow \boxed{\frac{d^2x}{dt^2} = -\omega^2 x}$$

$$\omega \equiv \sqrt{k/m}$$

$$x(t) = A\cos(\omega t + \phi)$$

$$[\omega] = [1/T] = s^{-1}$$

( A= “amplitude”, phi = “phase”, determined e.g. by initial position and velocity of the mass. ).

$$x(t+T) = x(T) \qquad T = 2\pi/\omega = 2\pi\sqrt{m/k}$$

*(DA!)

*

# SHO energy

Recall: $E = \frac{1}{2}m\dot{x}^2 + V(x)$ Find potential:

$$F = -\frac{dV}{dx} = -m\omega^2 x \longrightarrow V(x) = \frac{1}{2}m\omega^2 x^2$$

Plug in $x(t) = A\cos(\omega t + \phi)$ get E=constant:

$$E = \frac{1}{2}m\omega^2 A^2$$

Double check units:

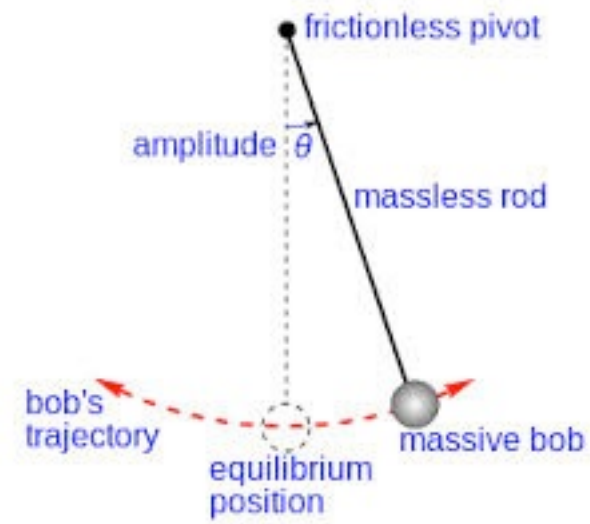
$$[E] = [mv^2] = [m\omega^2 A^2]$$

KE: $\frac{1}{2}m\dot{x}^2 = \frac{1}{2}m\omega^2 A^2 \sin^2(\omega t + \phi),$ PE: $\frac{1}{2}m\omega^2 x^2 = \frac{1}{2}m\omega^2 A^2 \cos^2(\omega t + \phi),$

# Any small* oscillation system: same math

E.g. pendulum:

$$mL^2\frac{d^2\theta}{dt^2} = -mgL\sin\theta \overset{*}{\approx} -mgL\theta$$




$$\rightarrow \boxed{\frac{d^2\theta}{dt^2} \approx -\omega^2\theta} \rightarrow \theta(t) = \theta_0\cos(\omega t + \phi)$$

$$\omega = \sqrt{g/L}$$

$$T = 2\pi/\omega = 2\pi\sqrt{L/g}$$

(DA!)

Advice: review this for our later use, waves.

# Week 1: fluids (ch 12)

**Density**: $dm = \rho \, dV$ $\qquad \rho = \frac{dm}{dV}$

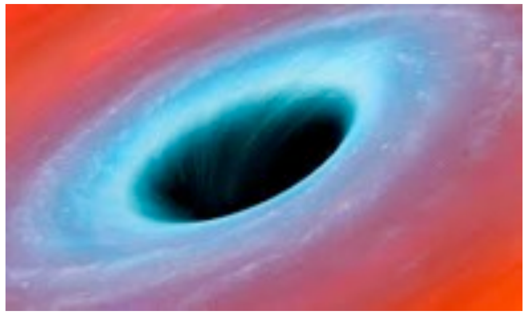
if it's constant, $\rho = m/V$

$\rho_{water} \approx 10^3 kg/m^3$ $\quad \rho_{concrete} \approx 2\rho_{water}$

$\rho_{lead} \approx 10^4 kg/m^3$ $\quad \rho_{gold} \approx 2\rho_{lead}$

$\rho_{neutron\ star} \approx 10^{18} (kg/m^3)$

Just for fun, black holes:



$$\rho_{black\ hole} \geq 1.8 \times 10^{19} (kg/m^3)(M_{sun}/M)^2$$

# FAQ, cont.

- Q:"Last time you told us the densities of water, lead, neutron stars, etc. Do we need to know all that data for the exams?" A: No! Any needed data will be given to you on the exam. No need to memorize stuff.
- The 3 x 5 card is for equations etc. If you forgot an equation, ask the TA and they might agree to write it on the chalkboard for you (at their discretion).

# Red scantron, X-101864-PAR-L

Grove general store

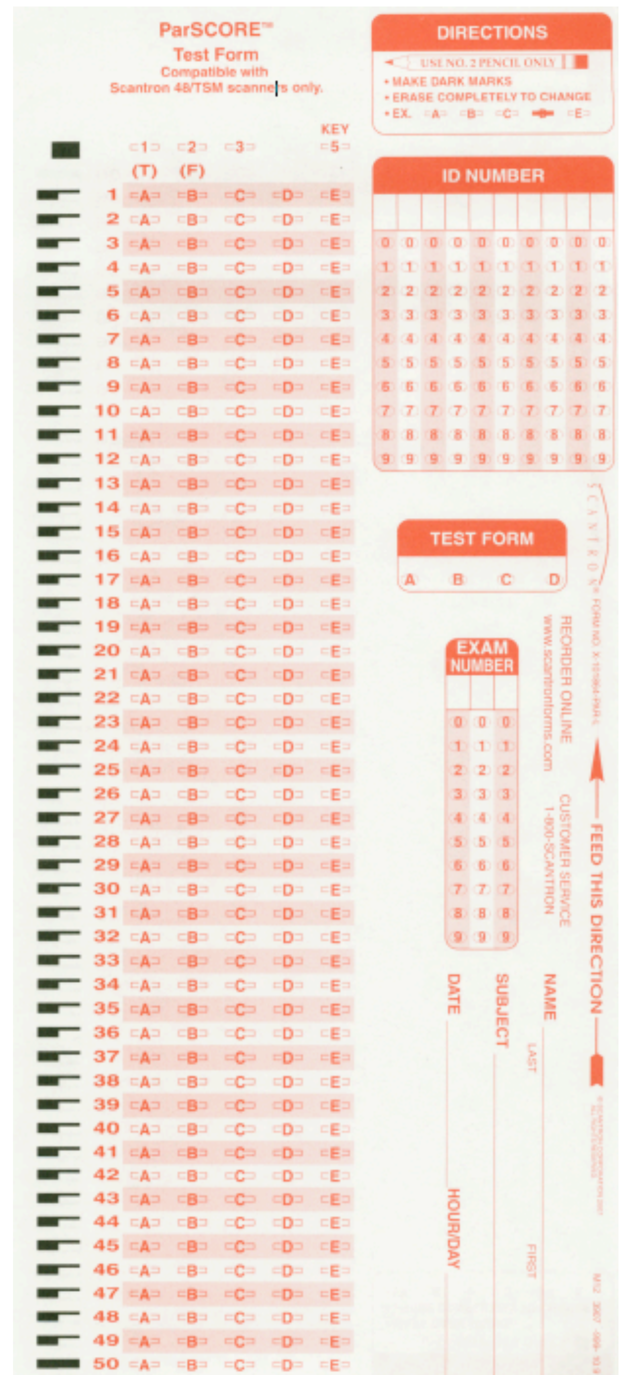
(cheapest),

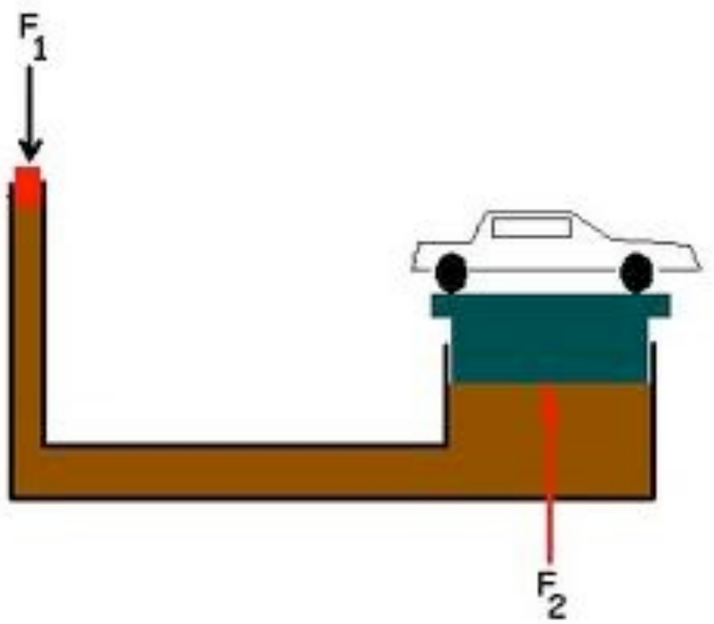
or bookstore.

Or buy from TA

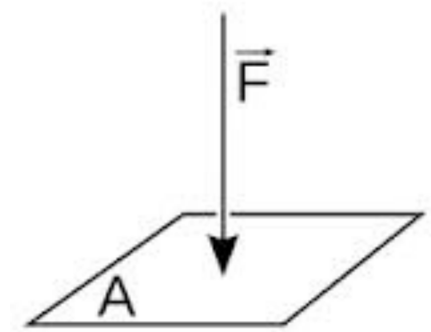
or classmates before

quiz (for $$$$)






# Pressure




(=scalar!)

(area)

$$d\vec{F} = -p\ \hat{n} da$$

$$\boxed{p = dF_\perp / da}$$

if constant, $p = F_\perp / A$

Ex: hydraulic press: pressure of fluid inside is almost constant (more soon), so $p = F_1/A_1 = F_2/A_2$

$F_2 = F_1 \cdot (A_2/A_1) \gg F_1$ Like a lever, can lift heavy object.

$$W_{by1} = F_1 \Delta x_1 = p\Delta V_1 \longleftarrow \Delta V_1 = \Delta x_1 A_1$$

$$W_{on2} = F_2 \Delta x_2 = p\Delta V_2 \longleftarrow \Delta V_2 = \Delta x_1 A_2$$

Same (no loss) **if** fluid is incompressible: $\Delta V_1 = \Delta V_2$

# "Gauge" Pressure

= Pressure ABOVE atmospheric pressure. E.g.

$p_{bike\ tire} \approx 100psi$ $p_{car\ tire} \approx 20psi$

Estimate area of each tire in contact with the ground

Bike: $\frac{1}{2}(200)/(100) = 1(in)^2$

Car: $\frac{1}{4}(4000)/(20) = 50(in)^2$

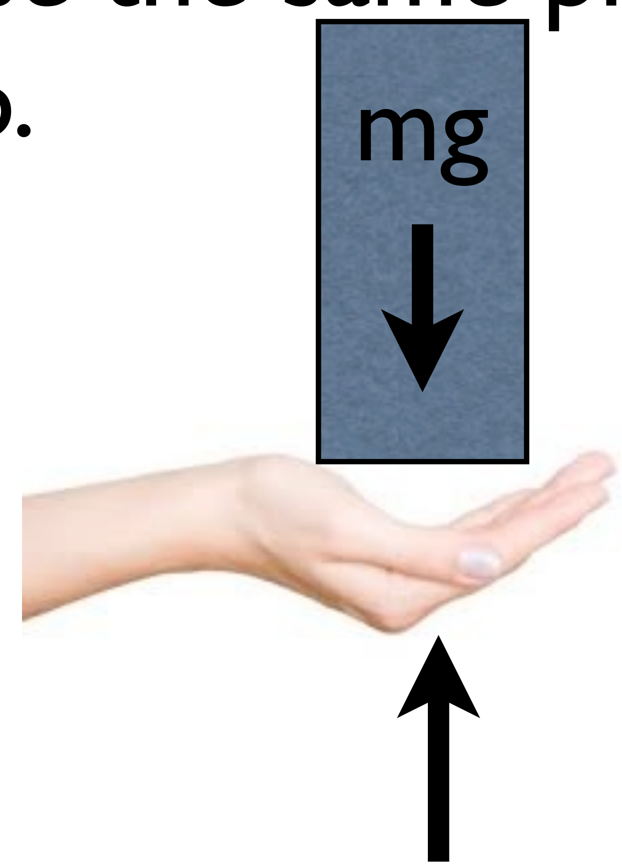
A=F/p

OK, makes sense

MKS: $1Pa = 1N/m^2$

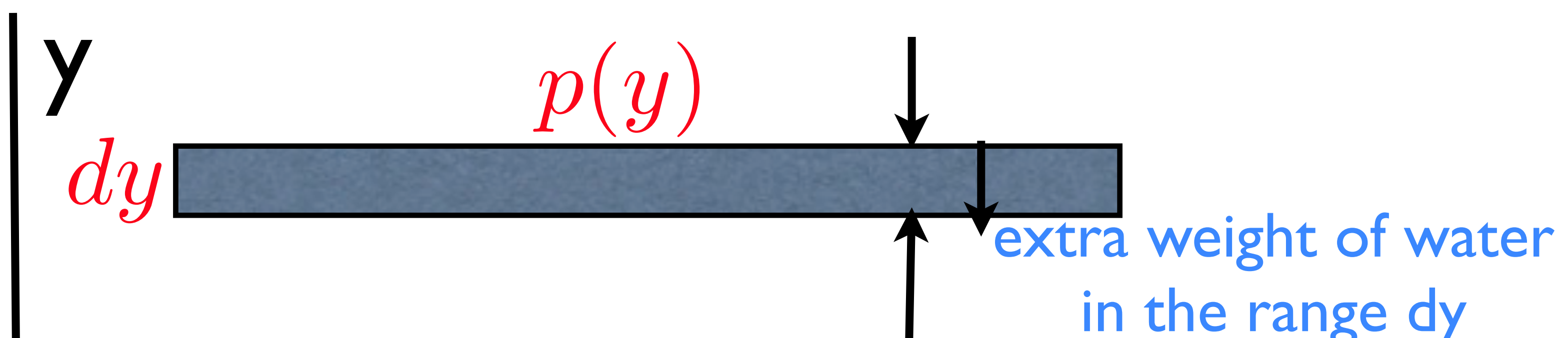
# Atmospheric pressure

At sea level, air pressure is around 101,000 Pa = 1atm. This is around 15 psi. E.g. on your hand, this is a force of around 150 lbs. Comes from the weight of all the air molecules in the atmosphere above us. It doesn't push our hand down because the same pressure is below our hand, pushing it up.



# Pressure and depth

Pressure in a fluid increases as depth is increased, because it includes the force contribution from the weight of all the fluid above it. Well known to divers: pressure increases as you dive deeper underwater. The pressure goes up by 1atm for every 10.3m of water depth.




$$p(y + dy) = p(y) + \rho g dy$$

Assuming constant density (incompressible) good approx for water, not air. Will do air later.

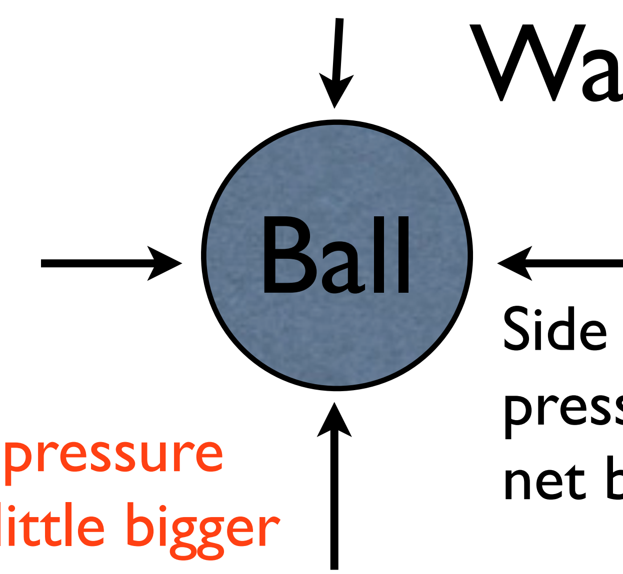
$$p = p_0 + \rho g \Delta y$$

# Pressure and Buoyancy

E.g. try to submerge a water polo ball underwater:

$$p = p_0 + \rho g \Delta y$$

Water




Side pressures cancel, bigger pressure below than above, so net buoyant force up.

pressure a little bigger here than on top

net force: $\vec{F}_b = -\int p d\vec{a} \neq 0$

Buoyant force from bigger force on bottom


Around 250 BC

# Buoyancy, cont.

King to Archimedes: how pure is the gold in my crown?
Archimedes mulled, and came to the idea in his bath.

Buoyant force: upward, equal to weight of the fluid displaced by the body. E.g.


$$m_{ship}\ g = \rho_{H_2O}\ g\ V_{displaced}$$

$$\longrightarrow V_{displaced} = m_{ship}/\rho_{H_2O}$$

Determines how much volume is hidden below the water surface in the picture.

# Icebergs

$W = gV_{total}\rho_{ice}$

$F_b = gV_{sub}\rho_{sea\ water}$

What fraction is above the surface?

$\rho_{ice} = 917\ kg/m^3$

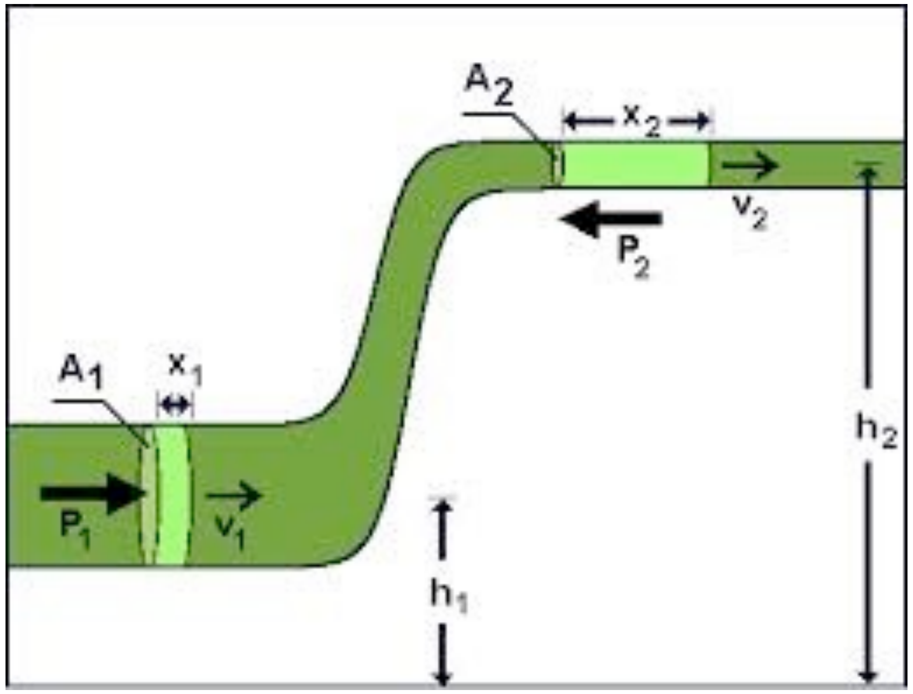
$\rho_{sea\ water} = 1024\ kg/m^3$

$F_b = W$

$$(V_{total} - V_{sub})/V_{total} = 1 - (\frac{\rho_{ice}}{\rho_{sea\ water}}) \approx 10\%$$

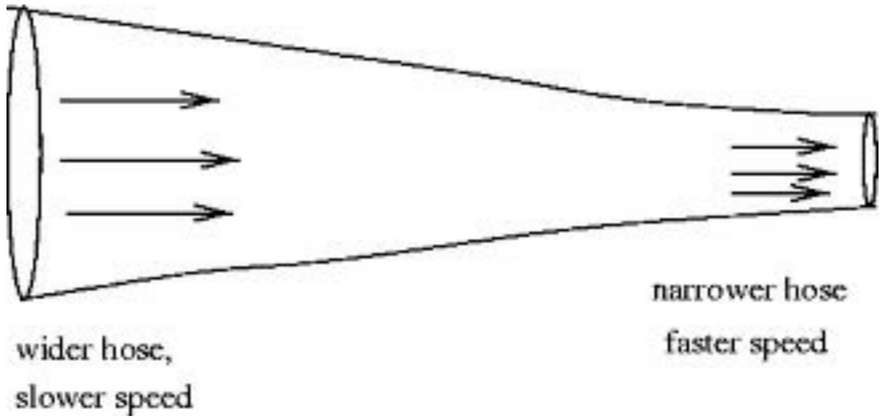
# Fluid Flow

If a fluid is (approximately) incompressible (like water),




$$dm = \rho A_1 v_1 dt = \rho A_2 v_2 dt$$

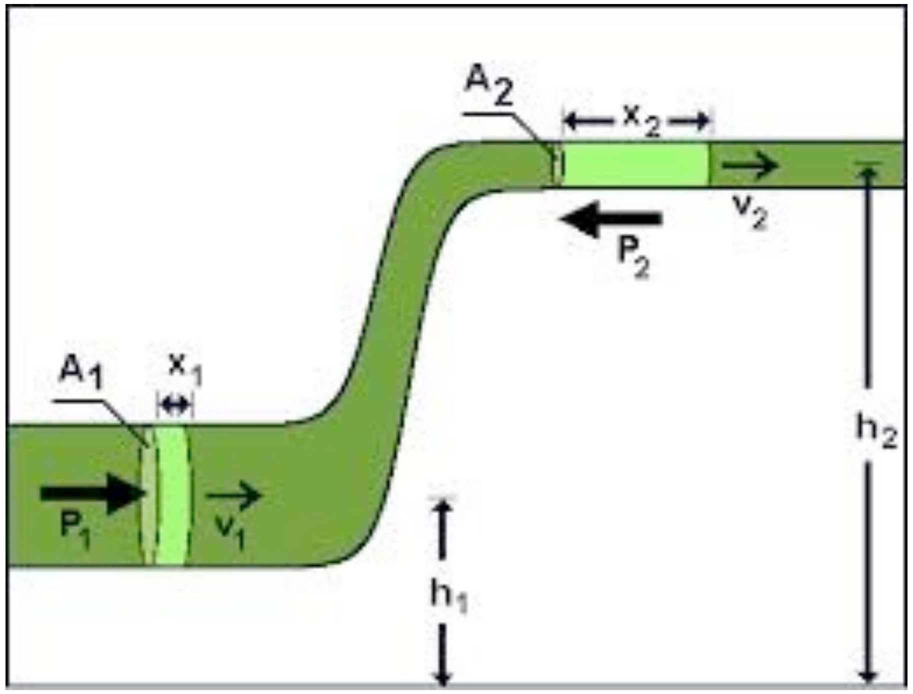
$$\longrightarrow \quad A_1 v_1 = A_2 v_2$$




compressible case: $\rho_1 A_1 v_1 = \rho_2 A_2 v_2$

# Bernoulli Equation

## Expresses conservation of energy




Work done **on** fluid element:

$$dW = p_1 A_1 dx_1 - p_2 A_2 dx_2$$

$$dW = (p_1 - p_2) dV$$ (suppose incompressible)

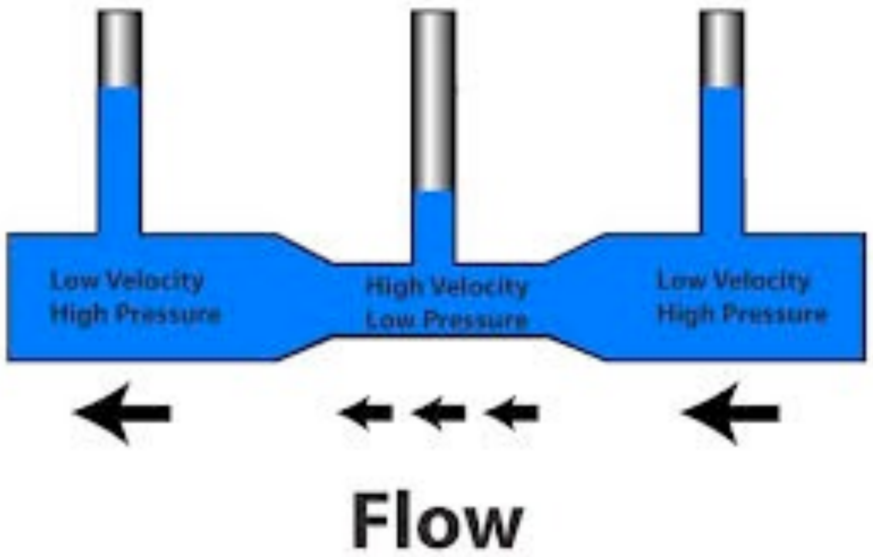
Change of its kinetic energy: $dK = \frac{1}{2}\rho dV(v_2^2 - v_1^2)$

Change of its potential energy: $dU = \rho dV g(y_2 - y_1)$

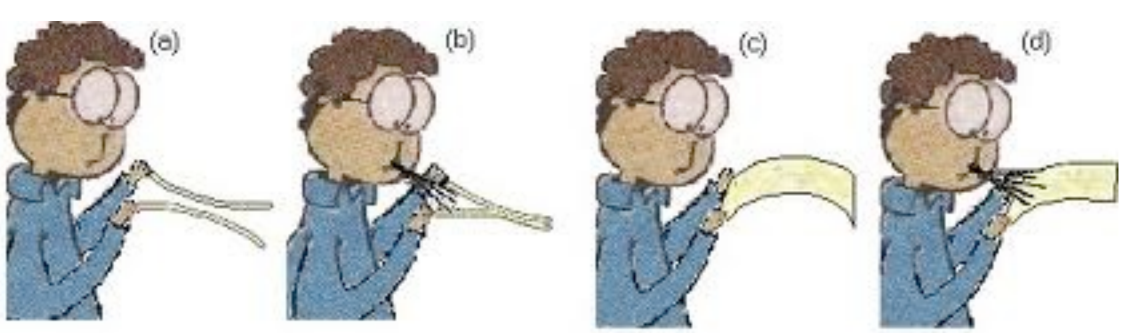
$$dW = dK + dU$$

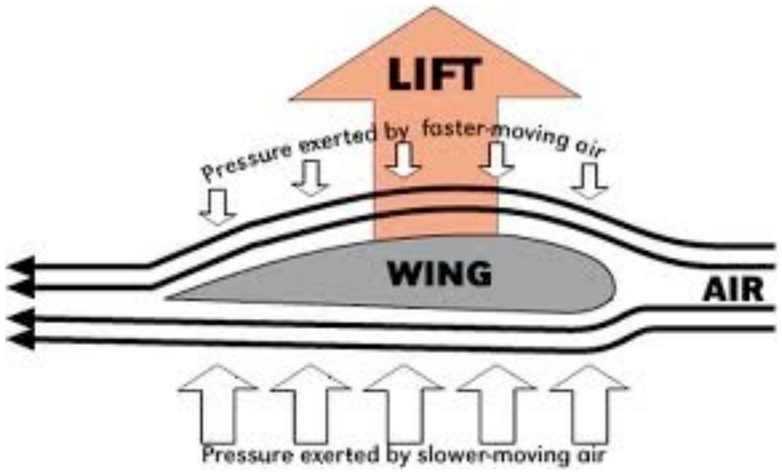
→ $$p + \rho g y + \frac{1}{2}\rho v^2 = const.$$

# Bernoulli, physically




$$p + \rho g y + \frac{1}{2}\rho v^2 = const.$$



# Large tank with small hole example

hole

$$p + \rho g y + \frac{1}{2}\rho v^2 = const.$$

(Approx.) Since small hole, and big tank.

Top: $p = p_{atm},\ y = h,\ v = 0.$

On side away from the hole

Bottom: $p = p_{atm} + \rho g h,\ y = 0,\ v = 0.$

Hole: $p = p_{atm},\ y = 0,\ v = \sqrt{2gh}$

Same velocity as an object dropped from a height h.

Equilibrium with outside at the hole.