Energy: Part 3 – moving on to Fluids!

Lecture 11:
- KE
- Water distribution

Reminders:
Reading quiz in just a second
Next week new materials…

Summary

- Energy and work so far:
  - GPE
  - Work done by friction (⇒heat)
  - Work done by applied forces (by me)

    $\boxed{W_{ext} - |W_{friction}| = \Delta PE + \Delta KE}$
  - Power
- This time
  - Kinetic energy
  - Water distribution (energy of running water)

New form of energy to think about.
Motional or kinetic energy.

KE = ½ mass x (velocity)^2

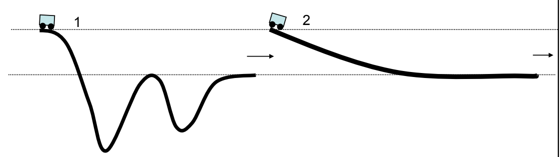
$$KE = \frac{1}{2} mv^2$$

Notice that this has the right units to be an energy:

KE = kg×m^2/s^2

Energy = N×m
= kg×(m/s^2)×m
= kg×m^2/s^2

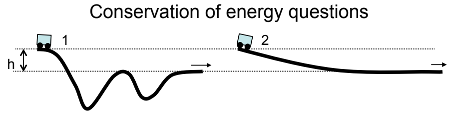
Conservation of energy questions



Two identical cars with really good bearings and solid tires roll on a very smooth, hard track (without friction). They start from rest and coast downhill, ending at the same height. How do their speeds compare at the end?

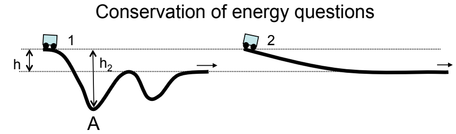
a. 1 is going much faster than 2
b. 1 is going a little faster than 2
c. 1 is going the same speed as 2
d. 1 is going a little slower than 2
e. 1 is going much slower than 2

Conservation of energy questions



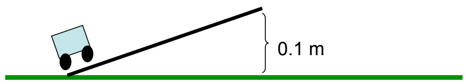
h = 20 cm
What is the speed of the cart at the end of the tracks?
a. 0 m/s
b. 0.2 m/s
c. 2 m/s
d. 20 m/s
e. 200 m/s

Conservation of energy questions



h_2 = 45cm
What is the speed of the cart at A?
a. Faster than final speed
b. Slower than final speed
c. Same as final speed

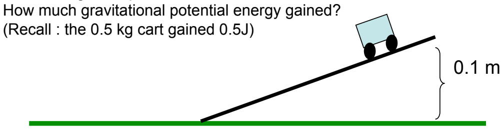
Push a 0.5 kg cart up 0.10 m.
How much gravitational potential energy (GPE) does it gain?



If we let it roll back down, how fast will it be going when it is back to where it started from?
a. 9.8 m/s , b. 1.4 m/s, c. 2 m/s, d. 1 m/s, e. 0.2 m/s

Conservation of energy questions

Push a 1 kg cart up 0.10 m.
How much gravitational potential energy gained?
(Recall : the 0.5 kg cart gained 0.5J)



Push the 1 kg cart up 0.10 m. How fast will it be going after it rolls back down?

a. same as the 0.5 kg cart, b. twice as fast, c. ½ as fast,
d. sqrt(2) x faster, e. sqrt(1/2) slower.

How high do balls go if you toss them?
(Conservation of energy - The easy method)

KE = 0
GPE = mgh

h?

KE = $1/2mv_0^2$
GPE = 0

$\cancel{W_{ext}} - |\cancel{W_{friction}}| = \Delta PE + \Delta KE$

Consider the changes between start and top of flight:

KE lost = GPE gained
$\frac{1}{2} mv_0^2$ = mgh

Example of "expert" approach:

Realize same physics principle applies to any situation where you're just trading between gravitational and kinetic energy
(No friction/external forces)

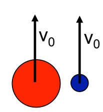
e.g. Cars on ramps, Balls in air -

Look different but SAME physics, SAME maths

How high do balls go if you toss them?

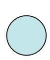
Consider 2 balls of different sizes, different masses tossed up with same initial velocity.
Compare the maximum heights that they reach:

a) Heavier ball goes higher
b) Same height
c) Lighter ball goes higher



Dropping cannonballs onto a board.

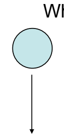
What is going to happen to the board?



What forms of energy are involved?
a. Gravitational potential energy
b. Gravitational potential energy and Kinetic energy
c. Kinetic energy and Thermal energy
d. Chemical energy, Gravitational Potential energy, and Thermal energy
e. Gravitational Potential energy, Kinetic energy, and Thermal energy

Dropping cannonballs onto board.

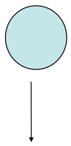
What is going to happen to the board?



measure the change.

Dropping cannonballs onto board.

Now drop the ball from twice the height.
What will the measured temperature rise be?



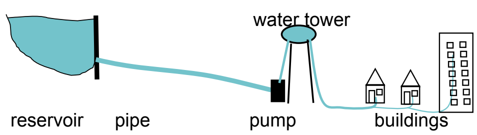
a. same, b. somewhat hotter, c. not as hot,
d. 10 times hotter.

Conservation of energy summary

- Often your best route for answering mechanics problems (especially when time is not involved)
- $W_{ext} - |W_{friction}| = \Delta PE + \Delta KE$
- Conservation of energy has been checked in thousands of experiments.
- This principle *always works*.
- There is no such thing as energy for free, or a perpetual motion machine!

When tackling a new situation/problem to get a solution or to make a prediction about behavior, usually the **first** thing a physicist does is figure out the different forms of energy, how much there is of each, and how it is being converted between various forms.

Water distribution

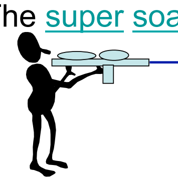


Where does the water flow?
What determines the water pressure in different homes/heights?
How fast does water flow out of a faucet?
How do you pump water out of wells?

ALL ABOUT CONSERVATION OF ENERGY!
GPE = mgh. KE = ½ mv^2 PPE = PV
Pumps do work (Force x distance)

(all of the physics of water distribution system)

The super soaker (e.g. squirt guns)

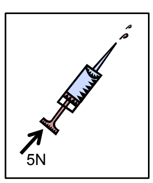


Pump up the pressure inside just a little bit and squirt. If we pump it up more, the water coming out will be:
a. going slower than before, b. going the same speed,
c. going faster.

Pressure potential energy (PPE)

What the heck is pressure anyway?

Pressure = $\frac{\text{Force}}{\text{Area}}$



Units: 1Pascal (Pa) = $1N/m^2$

The plunger of a syringe has an area of $1cm^2$.
I push the plunger with a force of 5N.
What's the pressure exerted by the plunger on the fluid inside?

a) 5N/m
b) 5 N/m^2
c) $500N/m^2$
d) 50000N/m
e) $50000N/m^2$

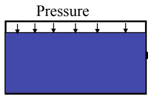
Pressure potential energy (PPE)

- New form of potential energy for fluids
- PE is the energy of an object (or fluid) due to its CONDITION (situation, surroundings etc)
- Water of mass m, at height h has associated GPE = mgh because of its (vertical) position
  - work (mgh) was done to get the water from ground to that height
  - Physical details of how the work was done or how water is being supported is not important
- Water of volume V at pressure P has associated PPE = PV
  - Work (PV) was done to pressurize the water
  - Physical details of how the work was done or how the pressure is being maintained are not important
- Check that PV has units of energy (J)

$PV = \frac{N}{m^2} \times m^3 = Nm = J$ ✓

Forms of energy in Super Soaker

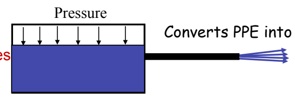
1. Pumping does work transforming chemical energy in my arm into PPE.



I apply a force, compress pump by a distance.

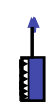
Work = force X distance.

2. When I pull the trigger, pressure does work on the water.



Converts PPE into KE = $\frac{1}{2}$ mv^2

3. When I fire upward, this KE turns into GPE

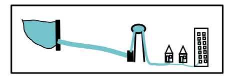


Energy in a water distribution system

- The same three forms of energy exist in a water distribution system
- If we add up energy in these forms, the sum must be constant.
- It just sloshes back and forth between forms!

PPE + KE + GPE = E_{total} (constant)

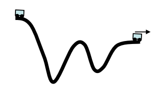
$PV + \frac{1}{2} mv^2 + mgh = E_{total}$



Since E_{total} is constant:

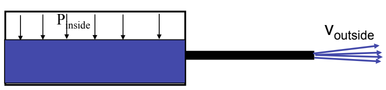
- If one thing changes, the other quantities must change correspondingly.
  - If pressure changes (water comes out of nozzle), v changes.
  - If height changes (go up in building), pressure or v changes, etc.

- Like the cart coasting up and down hills with no friction. Velocity and height are always connected
- ***If you know velocity and height at one place, can calculate it at all others.***



Apply Bernoulli to Squirt Gun

How is velocity of water out related to pressure inside gun?



$P + \frac{1}{2}\rho v^2 + \cancel{\rho gh} = E_{total\ per\ vol}$ Height constant so ignore GPE

$\Rightarrow$ **$P + \frac{1}{2}\rho v^2 = E_{total\ per\ vol}$ (constant)**

Inside gun: $P = AP + P_{pump}$, $v = 0$ $\Rightarrow$ $AP + P_{pump} = E_{total\ per\ vol}$

Outside gun: $P = AP$, $v_{outside}$ is big $\Rightarrow$ $AP + \frac{1}{2}\rho\, v_{outside}^2 = E_{total\ per\ vol}$

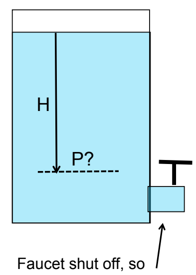
$$AP + P_{pump} = AP + \frac{1}{2}\rho\, v_{outside}^2$$

$$P_{pump} = \frac{1}{2}\rho\, v_{outside}^2$$

$$v_{outside} = \mathrm{sqrt}(2\, P_{pump} / \rho)$$

More on pressure

Here's a bucket of water with a faucet attached.
What is the pressure at a depth H?



Faucet shut off, so water is not moving.

Bernoulli's Equation:

$P + \frac{1}{2}\rho v^2 + \rho gh = E_{tpv}$

Compare water at surface and at depth H

v = 0 everywhere $\Rightarrow P + \rho gh = E_{tpv}$

- At surface: P = AP, h = 0

  $\Rightarrow E_{tpv} = AP$
- At depth H: $P = AP + P_w$, height = -H

  $\Rightarrow E_{tpv} = AP + P_w + \rho g(-H)$

E_{tpv} constant $\Rightarrow AP = AP + P_w - \rho gH$

$\boxed{P_w = \rho gH}$ $\boxed{P_H = AP + \rho gH}$

More on pressure

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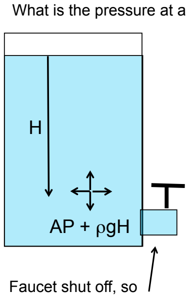
What is the pressure at a depth H?



Faucet shut off, so water is not moving.

Bernoulli's Equation:

$P + \frac{1}{2}\rho v^2 + \rho gh = E_{tpv}$

Compare water at surface and at depth H

v = 0 everywhere $\Rightarrow P + \rho gh = E_{tpv}$

- At surface: P = AP, h = 0

  $\Rightarrow E_{tpv} = AP$
- At depth H: $P = AP + P_w$, height = -H

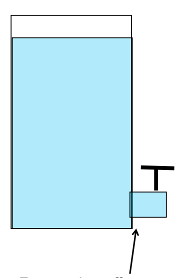
  $\Rightarrow E_{tpv} = AP + P_w + \rho g(-H)$

E_{tpv} constant $\Rightarrow AP = AP + P_w - \rho gH$

$\boxed{P_w = \rho gH}$ $\boxed{P_H = AP + \rho gH}$

This pressure is exerted equally in all directions

Atmospheric pressure

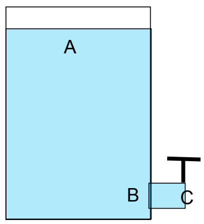


Faucet shut off, so water is not moving.

Pressure at surface of water
= Atmospheric pressure (AP)
≈ 100,000 Pa

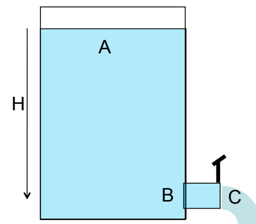
- Pressure due to air molecules hitting surface and exerting a force
- Always present at surface of earth
- Usually only interested in CHANGES in water pressure and AP cancels out
- If so can set zero of water pressure at AP (like setting zero of height somewhere convenient)

With the faucet off, the water is stopped at point C. Rank the pressures at the three locations shown.



a) $P_A < P_B < P_C$
b) $P_A < P_B = P_C$
c) $P_A = P_B = P_C$
d) $P_A = P_B > P_C$

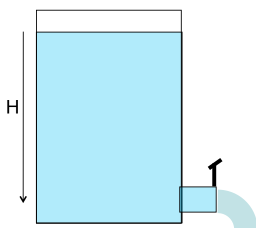
Now open the faucet. What is the pressure at point C, just outside the faucet?



a) Atmospheric pressure
b) The same as at B
c) Less than atmospheric pressure

Consider a little bit of water leaving the faucet. What is its velocity at the faucet exit?

(Hint: Question about pressure and velocity changes in fluid
⇒ Apply Bernoulli's Eqn)



a) Zero
β) ρgH
c) Sqrt(ρgH)
d) 2gH
e) Sqrt (2gH)

Bernoulli's Equation in Real Life

Total Energy per volume $= P + \frac{1}{2}\rho v^2 + \rho gh$

- This is a good approximation but it cannot be perfectly correct
- What type of energy does it ignore?
  ⇒ Think about a narrow pipe.

- Does not consider energy going into thermal energy- from friction with walls etc.
- For example, for high speed flow in a narrow pipe, more water molecules bounce off walls, creating significant friction and energy loss as heat
- But for most water distribution systems, friction can be ignored BE works very well.