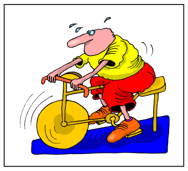
Energy and power



Lecture 10:
GPE
Work done by friction
What is a watt?
- Human power
Kinetic Energy

Reminders:
HW4 due Monday at midnight
Lectures can be rewatched online
Reading for Tuesday: Section 5.2

Reading quiz

1. In physics, the amount of work done is equal to
   a. The amount of heat energy generated
   b. The amount of energy transferred
   c. The number of calories I burn off
   d. My heart rate ×miles travelled
   e. Way too much (if you are referring to my Phys 1010 HW)

2. The gravitational potential energy of an object depends on:
   a. Its mass and its height above the ground
   b. g and its height above the ground
   c. Its mass, g, and its height above the ground
   d. Its mass, $F_{friction}$ and its height above the ground
   e. Its volume, g and its height above the ground.

Reading quiz

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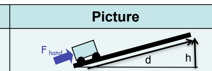
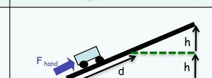
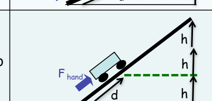
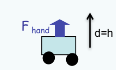
   d. Its mass, $F_{friction}$ and its height above the ground
   e. Its volume, g and its height above the ground.

Summary of data : Work done raising cart by h = 11.5cm

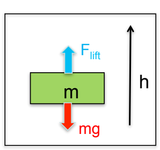
Method	Picture	F_{hand} (N)	d (m)	Work (J)
Shallow ramp		1N	2m	**2J**
Medium ramp		2N	1m	**2J**
Steep ramp		3N	0.66m	**2J**
Lift vertically		15.5N	0.115m	**2J**

Very different experiments but always get same answer for work done…..why is that?
Probably some important physics discovered here……..

General formula for work done when lifting stuff

In general, the work done raising any object of mass m by height h is always the same, however we do it.
Can we find a formula for the work done?

Consider lifting vertically:
F_{lift} = mg
Work done on object = $F_{lift} \times d_{//}$
= mg ×h
= mgh



Mass of object | Acceleration due to gravity | Vertical height raised **Really the change in h**

But the work done is independent of the lifting method
⇒W = mgh is true for a vertical lift
OR if you use a frictionless ramp of any steepness
OR any other frictionless lifting method

Introducing Gravitational Potential Energy (GPE)

Work done raising an object by height h = mgh

But work done = amount of energy changed

Chemical energy in my muscles (- mgh) → Work (mgh) → Gravitational PE of object (+ mgh)

GPE is the stored energy that an object has due to its vertical position (height)

⇒ Raising an object by height h raises its GPE by mgh

GPE = mgh (relative to h=0)

BIG CAVEAT:
h is the amount of distance it changes, not its beginning / final value!

To transfer energy to other objects requires work
Confusing Terminology: "WORK"

In "Everyday life language": we are doing work if it takes effort to do it!

In "Physics":

Work done by a force = Force × distance moved in direction of force

"Work" transfers energy to or from the object the force is acting on

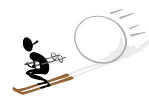
Outline

What we know about energy and work so far……

1. Energy is <u>always</u> conserved
2. Gravitational PE = mgh
3. Work is the transfer of energy form one form to another
4. $W = F \times d_{//}$

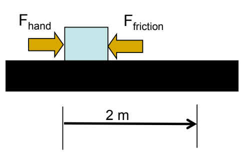
Last time we looked at work and energy in a FRICTIONLESS system

This is not realistic most of the time, so today we will include the work done by frictional forces



Work done by friction force

Pull 15N weight (wood block) across board at a steady velocity
Measure force needed.

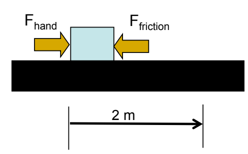


Constant velocity
$\Rightarrow F_{hand} = F_{friction}$
$\Rightarrow F_{friction} = 5$ N
(~ 0.3 x weight)

Slide block 2 m.
Work done by me on block = ?
a. 2 J, b. 5 J, C. 10 J, d. 20 J

Work done by friction force

Pull 15N weight (wood block) across board at steady velocity
Measure force needed.



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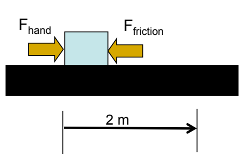
Slide block 2 m.
Work done by me on block = ?
a. 2 J, b. 5 J, C. 10 J, d. 20 J

Work = Force ×distance
Work done by me on the block is positive because
- F_{hand} and distance travelled are parallel
- F_{hand} GIVES energy to the block

Work done by friction force

Pull 15N weight (wood block) across board at steady velocity
Measure force needed.

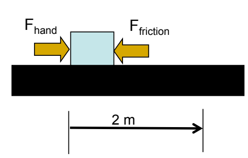


Constant velocity
$\Rightarrow F_{hand} = F_{friction}$
$\Rightarrow F_{friction} = 5$ N
(~ 0.3 x weight)

Slide block 2 m.
Work done by friction on block = ?
a. 2 J, b. -5 J, c. -10 J, d. -15 J

Work done by friction force

Pull 15N weight across board at steady velocity
Measure force needed.



Constant velocity
$\Rightarrow F_{hand} = F_{friction}$
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(~ 0.3 x weight)

Slide block 2 m.
Work done by friction on block = ?
a. 2 J, b. -5 J, c. -10 J, d. -15 J

Work = Force ×distance
Work done by friction on the block is negative because
- $F_{friction}$ and distance are anti-parallel
- $F_{friction}$ TAKES energy from the block

Friction and energy

- Work done by friction is always negative
  - $F_{friction}$ always opposite to direction of motion
  - Friction always takes energy away from moving object as heat
- Friction takes useful energy (motional) and turns it into heat energy (less useful) but energy is still conserved.
- Friction can be annoying
  - Wastes motional energy of cars, bikes etc so that engines have to work harder
- But is essential in our world
  - Enables cars to brake: turns motional energy to heat

Energy problems

Now we can handle problems with several different kinds of work/energy
- GPE
- W_{ext} (work done by hand, rope etc attached to the object)
- $W_{friction}$

How are they all related?
⇒ By CONSERVATION OF ENERGY

Consider Conservation of Energy for an object: block, car etc

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

Energy given by hand — Energy taken away by friction — Change in stored energy (GPE, EPE) — Change in motional energy

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Consider C of E for an object: block, car etc

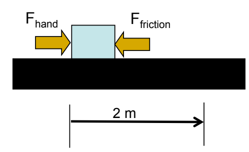
$$W_{ext} - |W_{friction}| = \Delta PE + \Delta KE$$

Deposit — Withdrawal — Change in account balance

Reminder

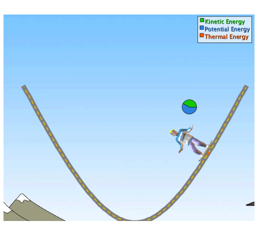
Push 15N weight (wood block) across board at steady velocity
Measure force needed.

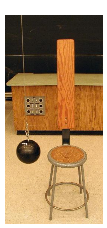
Constant velocity
⇒ $F_{hand} = F_{friction}$ = 5N
(~ 0.3 x weight)



Slide block 2 m.
Work done by me on block = 10 J
Work done by friction on block = -10 J

Real Life?





http://phet.colorado.edu/en/simulation/energy-skate-park-basics

Homework – a some calculations

- "Expert" approach:
  - Understand and apply (few) basic concepts.
  - Realize doing same problems over and over again.
  - Different form but applying same concepts ⇒ easy.
  - Can handle unseen problems in tests.
- "Novice" approach
  - New problem, start from scratch each time ⇒ hard.
  - Try to memorize problems for test – impossible
- "Expert" approach outside of physics
  - Many aspects of life (employment) governed by a few basic concepts
  - Understand and apply these to solve new and unexpected problems
  - VERY valuable skill in the workplace
  - Start developing this skill now!!

Human energy

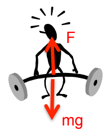
(or how long must I spend on the stairmaster to burn off my chocolate bar?

What the heck is a Joule??

1J (work or energy) = 1N (force) x 1m (distance)

How much work do I do benchpressing a 40kg (90lb) barbell 0.5m?

W = F ×d
= mgh
= (40) (9.8) (0.5)
= 196 J



But how does that compare to a chocolate bar?

Calories are just another unit for measuring energy
1 food calorie = 1kcal = 1Cal = 4184 J.

Decent chocolate bar has 400 kcal or 1,673,600J
So it has the same energy required for 8,539 Benchpresses!

Power

Power = Energy/second.

P = E / t

Units: 1 Watt = 1J/s.

⇒ 100 watt light bulb means 100 Joules electrical energy/sec.

⇒ Does that make sense? Why do we measure power of bulb instead of energy?

⇒ What do we pay the utility company for?

100+ W of heat per person by just sitting here!
No wonder lecture theatres, concert halls etc get hot and stuffy when full!

How much useful power (work/second) can a human sustain over a 1 minute interval?

a. 5 W
b. 50W
c. 500W
d. 5000W
e. 50,000W

Humans output over 100W of heat energy just sitting still

Active human can generate 800J of useful mechanical work per second (800W of useful power) for a short period. (750W ~ 1HP)

How much of our food energy goes into useful work?

- Tour de France rider: 400 W for ~1 hour, *[~1/2 horsepower]*
- Athletic man: ~150 W on bike for 10 hour day

So if I go to the gym and pedal at 150W output, I could

a) Power the ac for the entire building
b) Power a space heater
c) Power a lightbulb
d) Power not enough to run anything of interest

How much of our food energy goes into useful work?

• How much force x distance can person do?
⇒ Easy to measure with stationary bicycle.
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www.egreenrevolution.com
www.rerev.com

Sounds great, we could (partially) power the world while people get fit at the same time but what's the catch?
…….lets keep thinking…………

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• How much work does he do (expressed as Cal) during 10 hour ride?
(1 Cal = 4184J)

a. 2140 Cal, b. 1290 Cal, c. 150 Cal d. 12000 Cal

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Work (J) = (150J/s)×(60×60×10s) = 5,400,000J
Work (Cal) = (5,400,000 J) × $\frac{1Cal}{4184J}$ = 1291Cal

• But he eats ~ 5800 Cal/day
Where does the rest of the energy (5800-1291=4500 Cal) go?

a. chemical, b. sweating, c. light, d. heat, e. odor

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80% of our chemical energy intake is lost as heat energy
As machines we are only 20% efficient…
Similar efficiency to an internal combustion engine

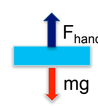
So back to our human powered gym idea……

• Pedaling on the bike at 150W I produce 150J of useful electrical energy each second
• And 4×150 = 600J of heat energy
• The ac unit in the gym uses ~200J/s of electrical energy to remove the heat I generate from the room and keep the temperature constant

• So at the gym
  - I produce 150W of electrical energy by pedalling
  - I consume 200W of electrical energy keeping cool
  - I have a net power CONSUMPTION of 50W…………
  - Ignores energy used for lights, car ride there, warm shower……..

• You' d be 'greener' (consume less power) just going for a regular bike ride outside
• Or better yet ditching the car and doing your errands on a bike

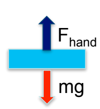
Recap



Applied force is the same if book stationary or moving up/down with constant velocity (F_{hand}= weight =mg)

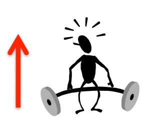
What about the amount of work done by me?
Do I do more work (get tired more quickly) lifting book up and down or just holding it up?
a. same, b. more work if lifting c. more work if holding it up

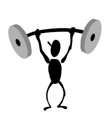
Recap



Applied force is the same if book stationary or moving up/down with constant velocity (F_{hand}= weight =mg)

What about the amount of work done by me?
Do I do more work lifting book up or just holding it up?
a. same, b. more work if lifting c. more work if holding it up





Work = force x distance, only do work on weights if moving through a distance by lifting. If holding stationary then distance and work = 0.

Hard question – putting ideas so far together

I can only push with a force of 10 N, but I want to move a 3 kg mass up to a height of 0.5 m.
How steep a ramp should I make (keeping it as short as possible)?

a. can' t do it, takes 29.4 N to raise a 3 kg mass.
b. a 50% grade (1m along ramp for 0.5 m up)
c. 1.5 m along ramp and 0.5 m up
d. 2 m along ramp and 0.5 m up
e. 2.5 m along ramp and 0.5 m up

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Remember 2 new ideas:
a) Same work to go to same height (Work = mgh)
b) $W = F \times d_{//}$

a)Imagine we lift straight up to height of 0.5m at constant speed
$W = F\times d_{//} = mg \times h = 3 \times 9.8 \times 0.5 = 15J$
This work is the same however we get the mass to height h

b) $d_{//} = W/F$
$= 15J/10N = 1.5m$

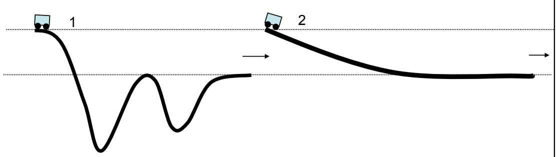
New form of energy to think about. Motional or kinetic energy.

KE = ½ mass x (velocity)²

$KE = ½ mv^2$

Notice that this has the right units to be an energy:
$KE = kg\times m^2/s^2$
$Energy = N\times m$
$= kg\times(m/s^2)\times m$
$= kg\times m^2/s^2$

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