

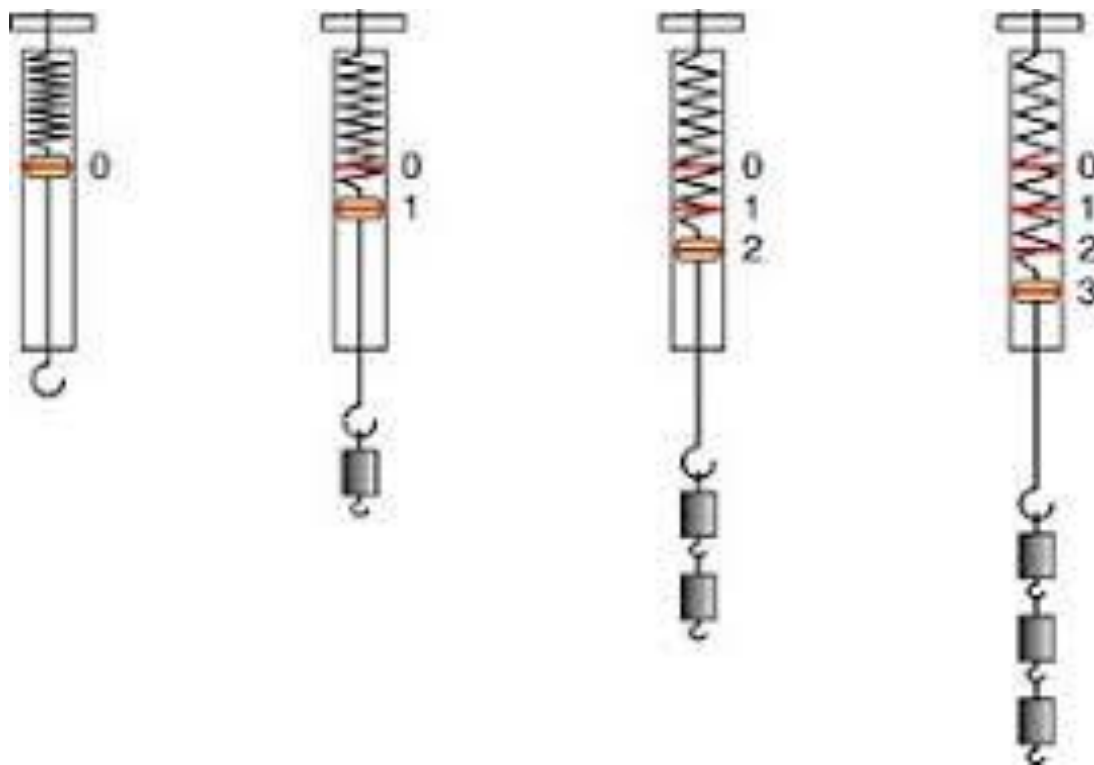
Pharmacy : Physical bases of biophysics

Dynamics, Work, Energy



Schay G.

Dynamics and Statics

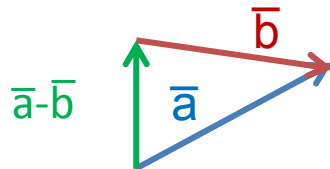
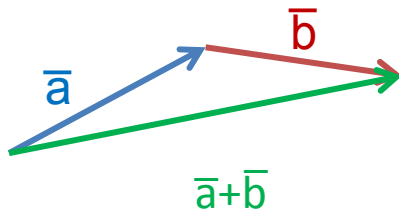


When is it dynamics, and when statics?

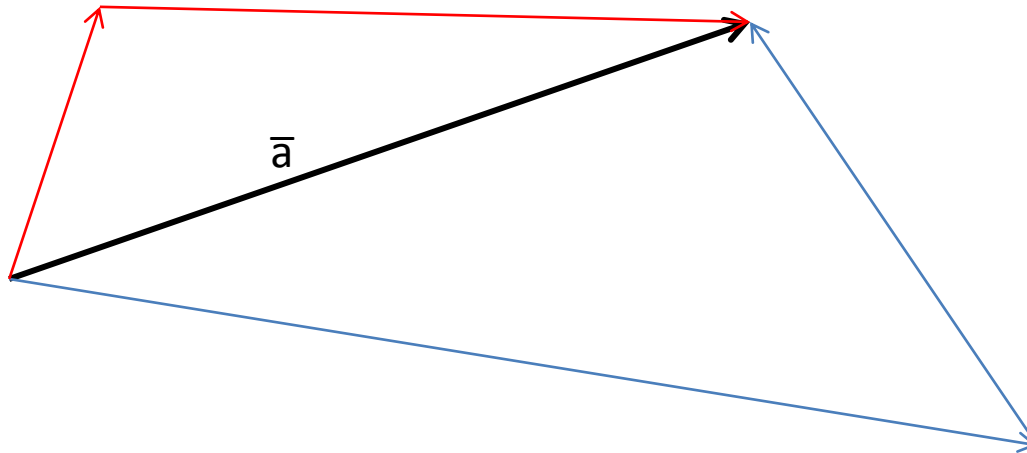
Force: something which describes an interaction.

VECTOR: has size AND direction.

Vector algebra: calculation rules with vectors:



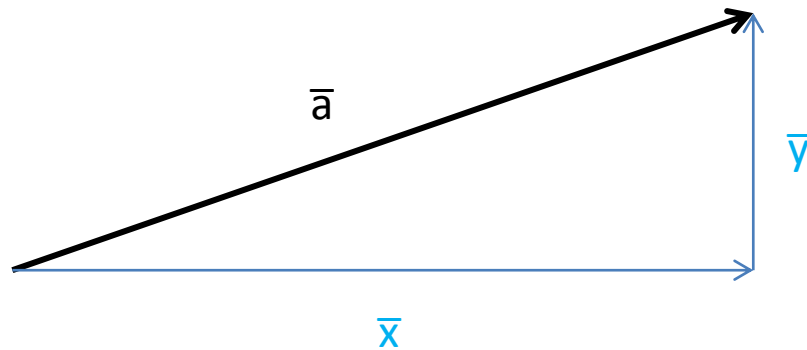
The algebra makes it possible to **break up** vectors, just like numbers.
Az algebra lehetőséget ad a vektorok FELBONTÁSÁRA is!
($10=3+7$ or $10=4+6$ or $10=5.01 + 4.99$, etc)



We have endless possibilities, with size and direction being free.

We always choose the breakup which makes our life easy ☺

Usually we use two INDEPENDENT directions, so we can focus on the directions one by one.



Everything we calculate using vectors enables a breakup.

Dynamics: we study the **movement** of bodies (objects)

A lot of things are vectors:

position(r**)** : a vector in a given coordinate system (eg. inercial system) pointing from the 0 point to the object under study.
(of course we use a breakup into x,y,z directions all perpendicular...)

velocity (v**)**: the change of the position over time. $v = \frac{\Delta r}{\Delta t}$

acceleration (a**)**: the change of speed over time. $a = \frac{\Delta v}{\Delta t}$

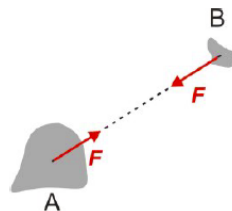
Newton's Laws:

I : if $a=0$ then the sum of forces is 0 too (they cancel each other).

(All bodies stay rest, or move with a steady speed unless some interaction forces them to change their speed.)

II: $\sum F = m * a$

III: force-counterforce



WORK

def: There is work being done IF some object changes it's state of motion parallel to a force.

(Coriolis 1826, water removal from mines, how many buckets of water can a steam engine elevate...)

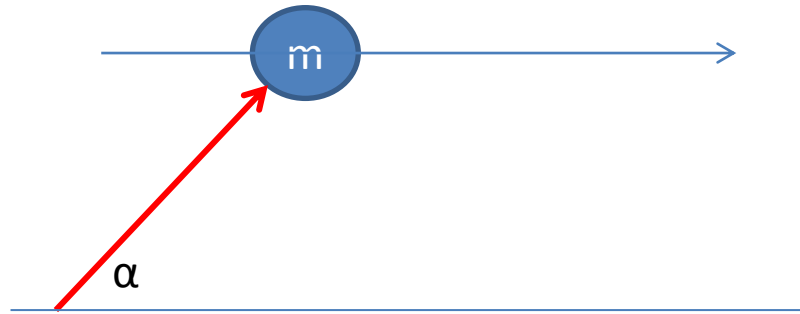


IF the force is parallel to the movement, then

$$\Delta W = F * \Delta r$$

Or in a more usual form: $W = F * s$

If they are not parallel, then only the parallel portion of the force is used.

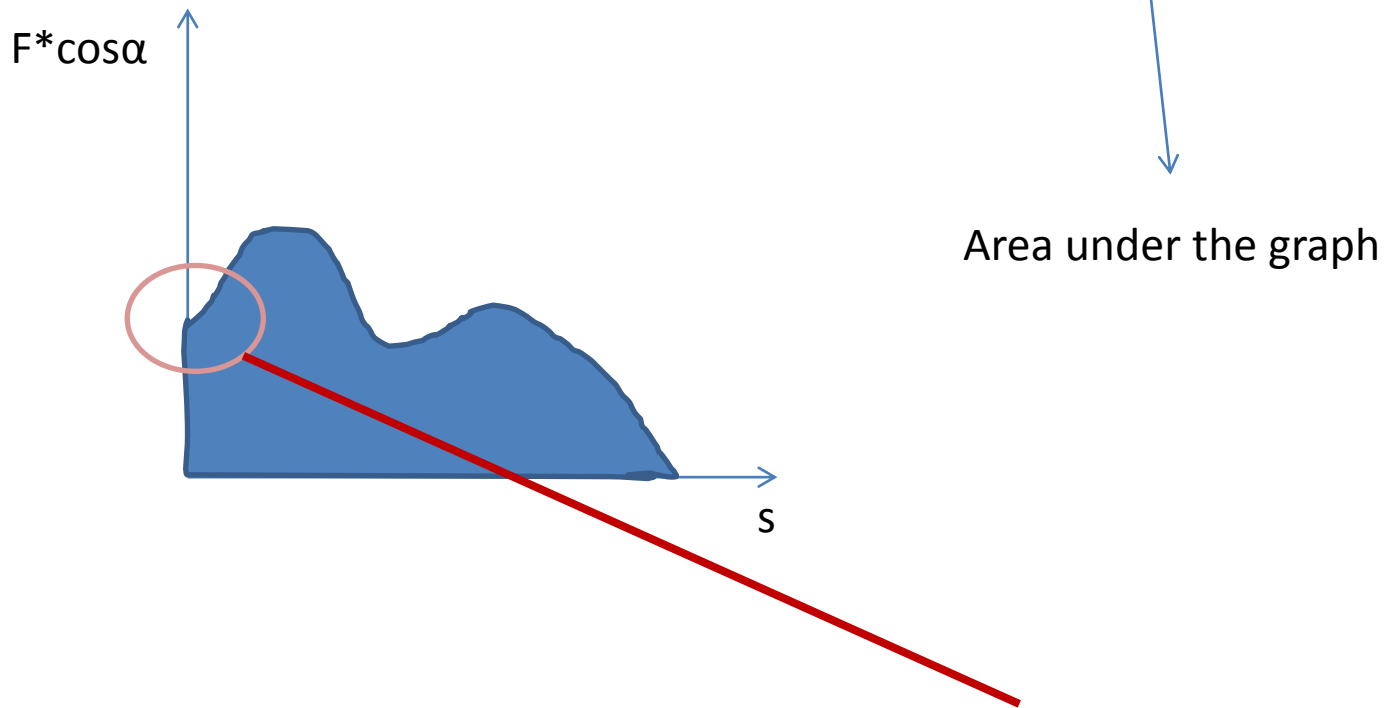


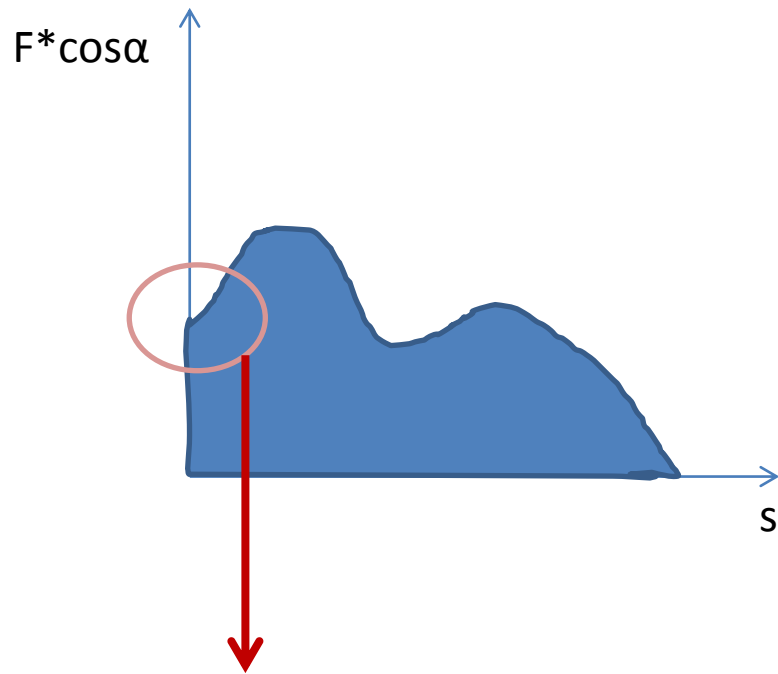
$$W = F \cdot s \cdot \cos(\alpha)$$

Unit:

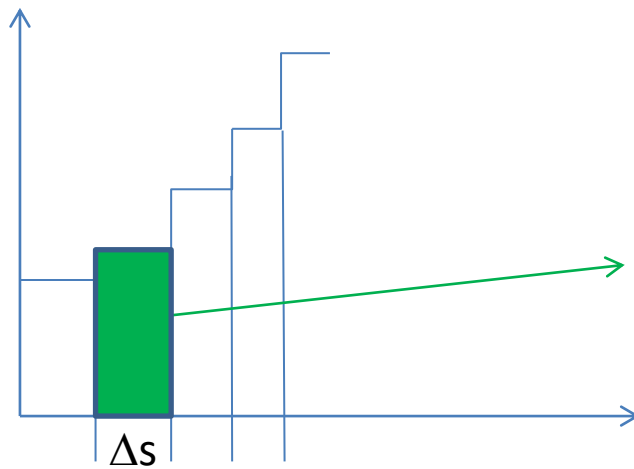
$$[W] = [F][s] = \text{N} \cdot \text{m} = \text{kg} \cdot \text{m}/\text{s}^2 \cdot \text{m} = \text{kg} \cdot \text{m}^2/\text{s}^2 = \text{Joule (J)}$$

If the force is changing, then we break up the movement into small pieces, and add them





Area under the graph



$$F \cdot \Delta s = \Delta W$$

Δs is VERY SMALL!
LOT of small pieces...

POWER:

Def: work done over time.

$$P = \frac{\Delta W}{\Delta t}$$

Unit: J/s = Watt.

ENERGY:

Def. Energy is a conserved quantity related to an object, which can only be changed by work or heat transfer.

so: $\Delta E = W$

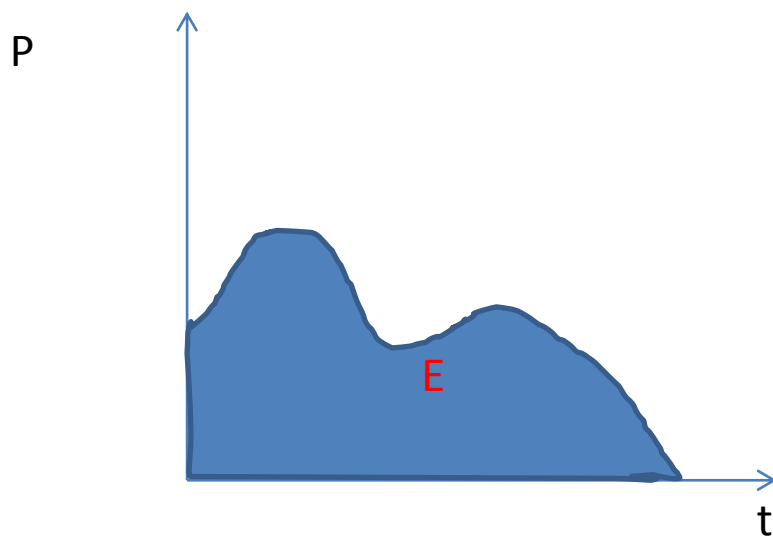
Why is this good?

Since it is conserved, there is a CONSERVATION LAW.

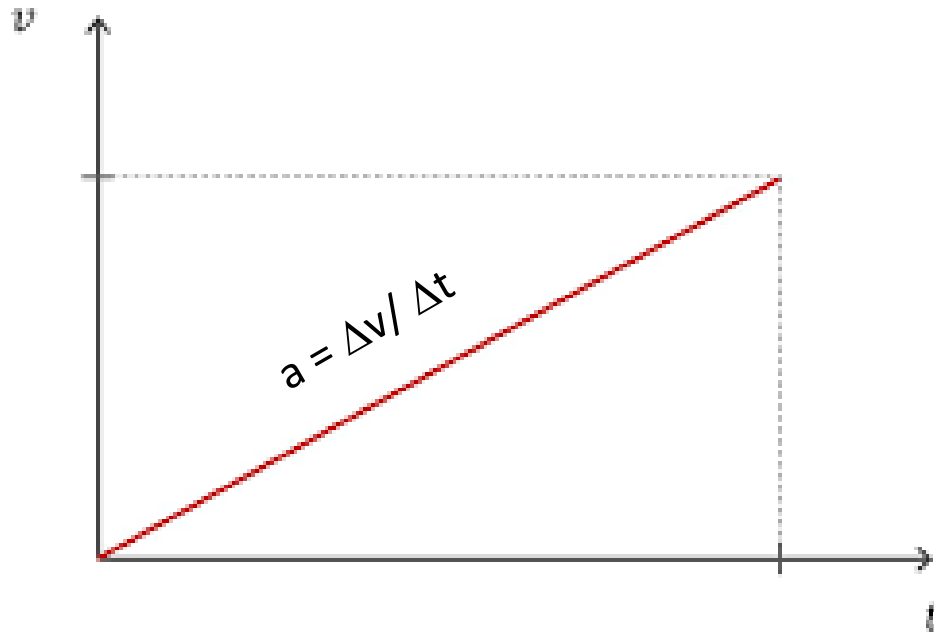
Eg: Newton III -> two forces, **energy exchange, BUT the SUM is stays same!**

Power can be expressed with energy as well: $P = \Delta E / \Delta t$

Since there is a change, the idea of area under the graph can be re-used here



Kinetic energy:



Let's start an object from rest.

$F = m \cdot a$, de $v_0 = 0$.

The way (pathlength): $s = v_{\text{average}} \cdot t$

But from the graph we see: $v_{\text{average}} = v/2$

so>: $s = v/2 \cdot t$

but $a = v/t$ (steady acceleration)

since $W = F \cdot s = m \cdot a \cdot s = m \cdot (v/t) \cdot (v/2 \cdot t)$

so

$$W = \Delta E_{\text{kin}} = \frac{1}{2} \cdot m \cdot v^2$$

N.B.: s is of course the area under the curve.

Rotational kinetic energy:

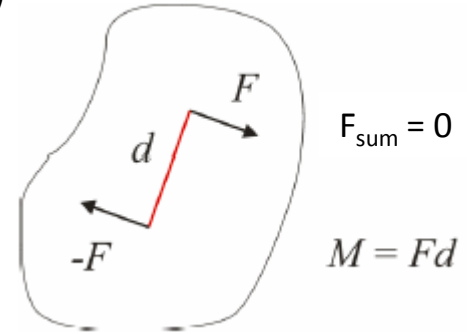
$$\omega = \frac{\Delta\alpha}{\Delta t} = \frac{2\pi}{T} = 2\pi f$$

Angular velocity (instead of velocity)

$$\frac{\Delta\Theta\omega}{\Delta t} = M$$

Torque (M) (instead of the simple force),
Newton : to change rotation we need
torque.

If $M=0$ then ω (or $\Theta*\omega$, just like $m*v$)
does not change.



$$E_{rot} = \frac{1}{2} \theta \omega^2$$

Proof: same as Kinetic energy, but angular velocity over time graph is used...

Potential energy:

In a conservative force field the work done on an object only depends on the starting and end positions of the object.

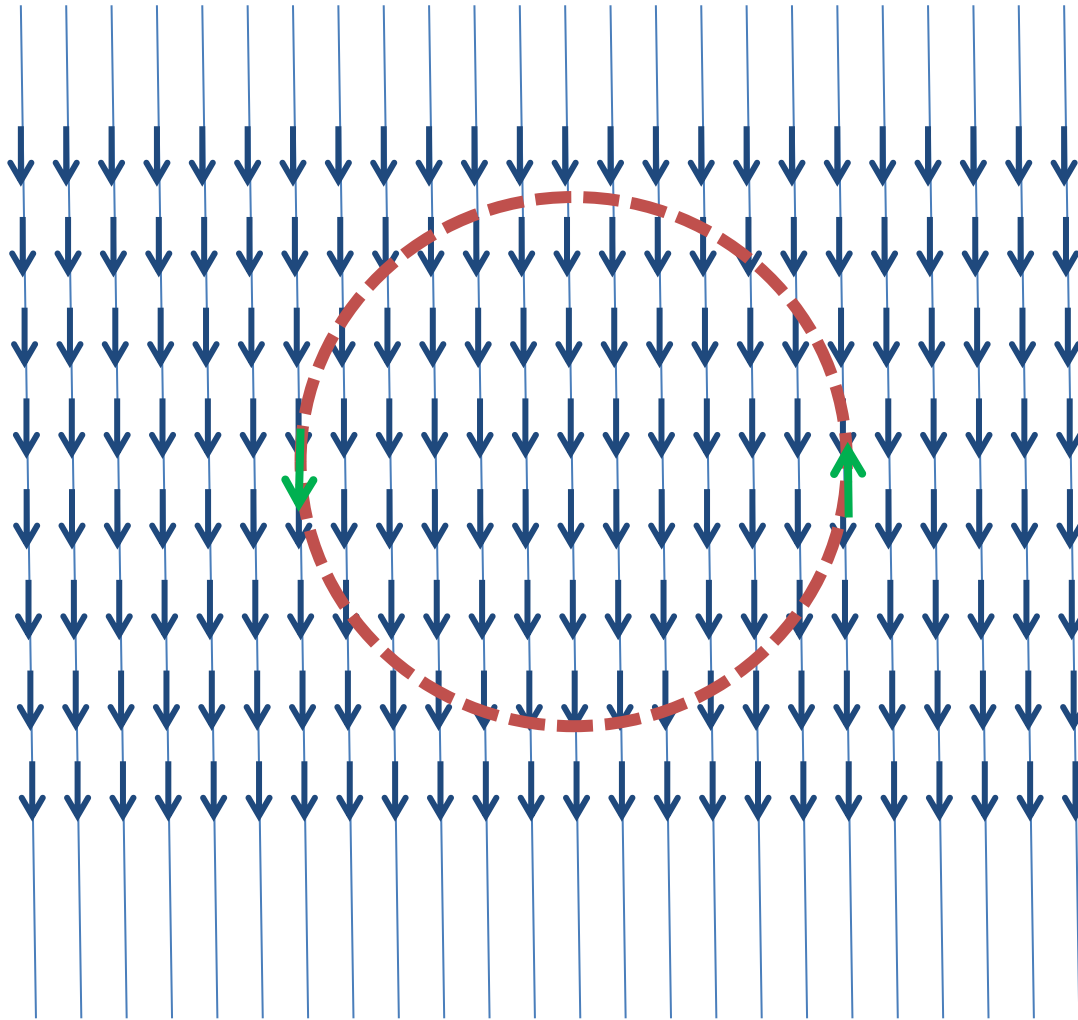
In this case it is useful to define the potential energy, so that the energy change can be attributed to the position directly.

forcefield: The presence of a force, which can be ordered to every point in space.
examples: gravity, Coulomb force, etc.

Potential energy: That amount of energy which can be used to do work if the object moves towards, and into the 0 (origin) point of the coordinate system.

gravity : conservative force field.

It is easy to check: on a closed path the total work is 0

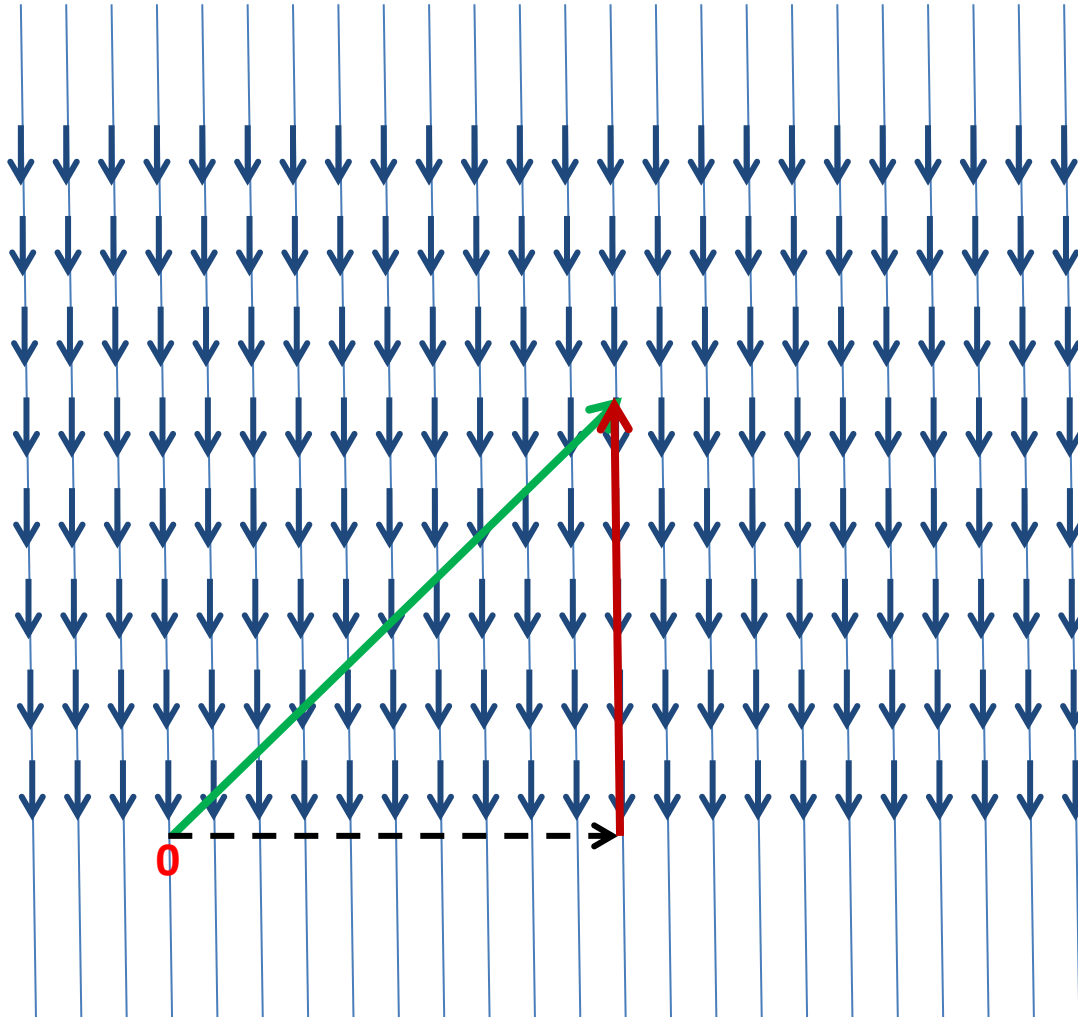


$$\bar{G} = m * \bar{g}$$

In the sum of the $W=F*s$ terms we have cancelling pairs everywhere...

If we set the origin, then the potential energy calculation is easy.

$$\bar{G} = m * \bar{g}$$



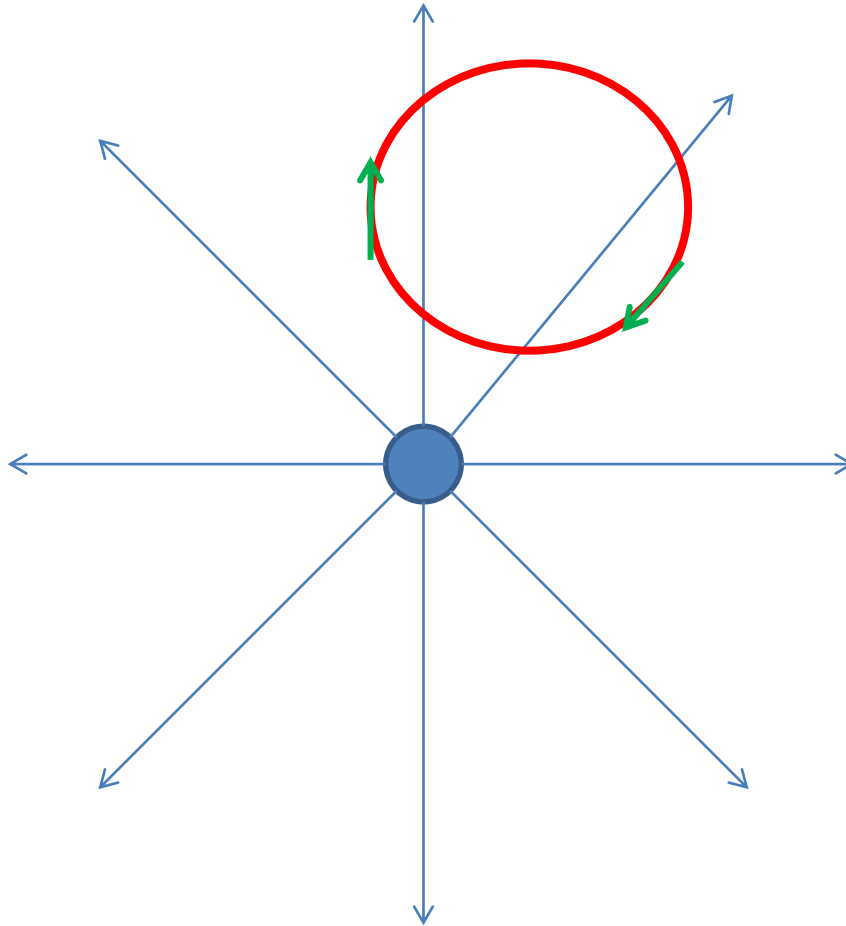
$$E_{\text{pot}} = G * h = m * g * h$$

IF
We move parallel
to the force lines,
but opposite to
the direction of
the force

**Only the
parallel
component
counts!**

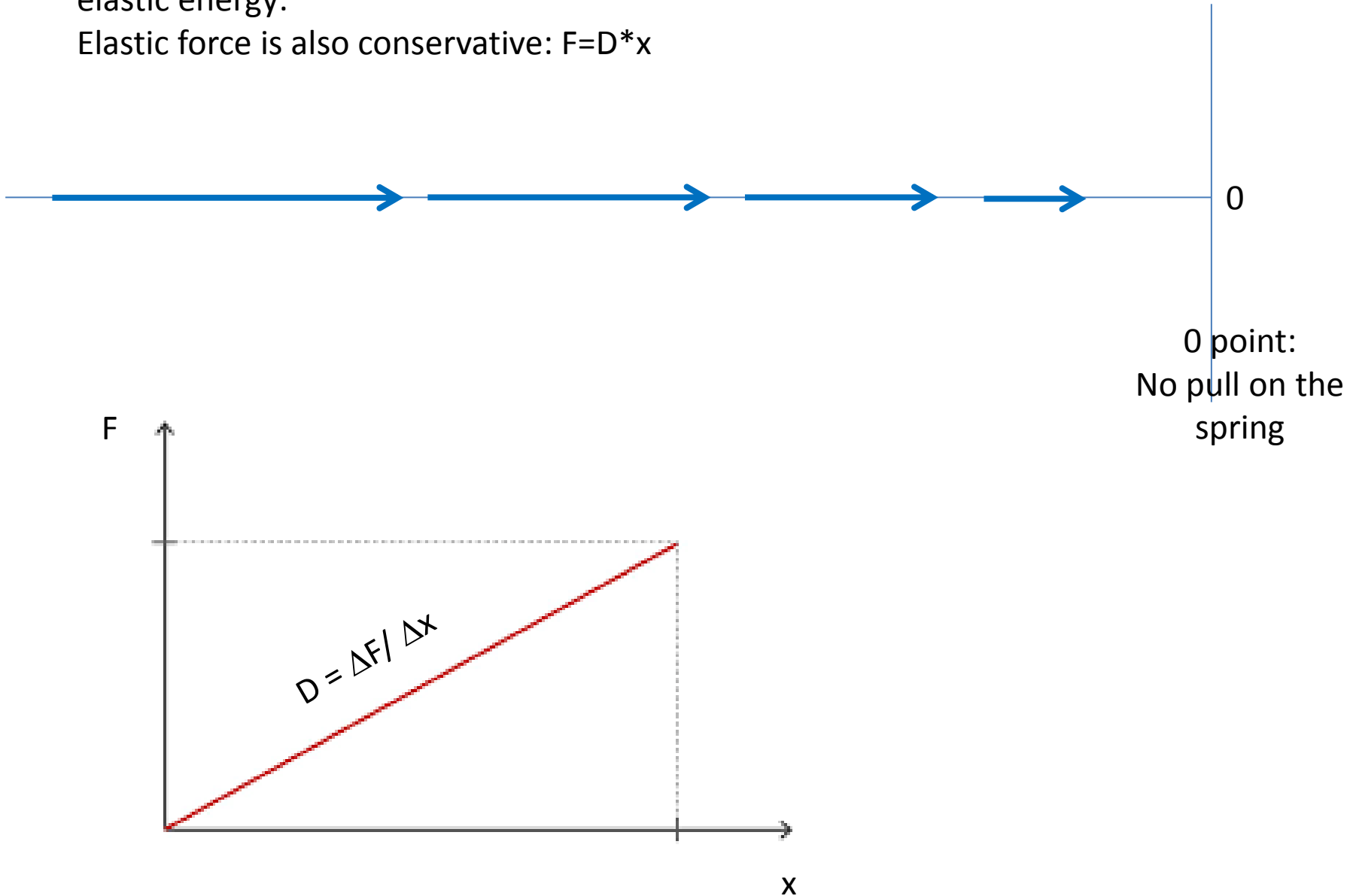
A breakup is of course useful here 😊

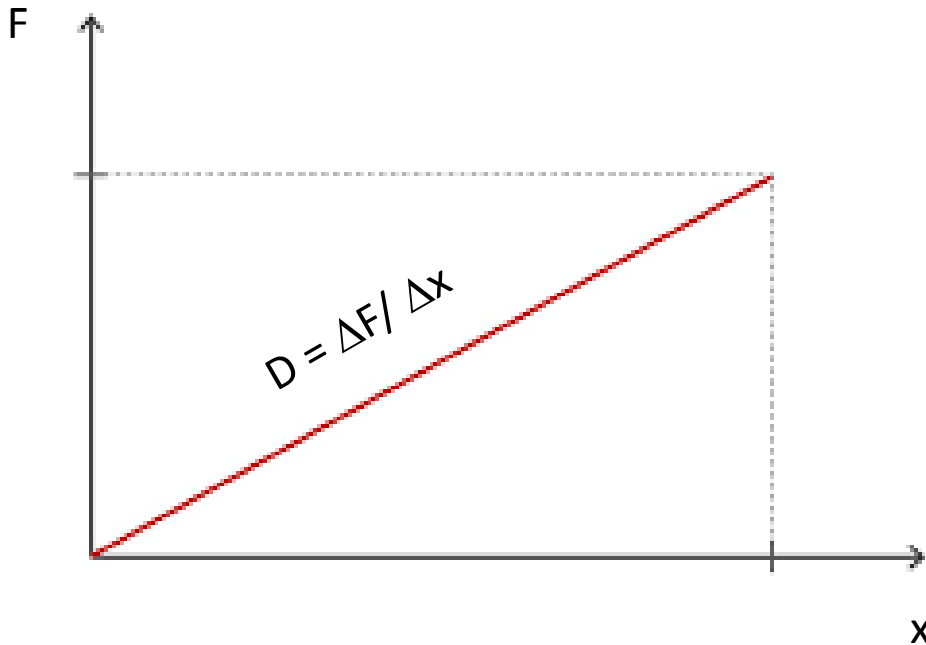
Electric potential: here we also have a conservative field.
See later for more details...



elastic energy:

Elastic force is also conservative: $F=D*x$





So just as with the kinetic energy, totally the same logic can be re-used here:
(you need to understand it only once! That is the beauty in phys/math)

$W = F_{\text{elastic, average}} \cdot s$, de $F_{\text{elastic}} = F_{\text{spring}} = D \cdot x$, and $x=s$ just the letter we used is different here.
But we have a straight line, so $F_{\text{elastic, average}} = F/2$.

With that **$W_{\text{elastic}} = \frac{1}{2} \cdot D \cdot x^2$**

Mass/energy equivalence:

This we can not see in everyday life, but in nuclear physics it is very common...

$$E=mc^2$$

So mass and energy are not so much separated as we might think.

atomenergy.

ENERGY-CONSERVATION

In a closed system the sum of energies is constant, but they can be transformed into each other freely.

There are hundreds of years and billions of experiments proving it....

Probably there is really no energy out of vacuum...

Useful units:

$$\text{Joule} = \text{kg} \cdot \text{m}^2 \cdot \text{s}^{-2} = \text{N} \cdot \text{m}$$

$$1 \text{ kcal} = 4184 \text{ J} \quad \text{kilo-calories (heating of water)}$$

$$1 \text{ Wh} = 3600 \text{ J} \quad \text{Watt-hour}$$

$$1 \text{ eV} = 1.6 \cdot 10^{-19} \text{ J} \quad \text{Elektronvolt}$$

$$1 \text{ BTU} = 1055 \text{ J} \quad \text{British Thermal Unit}$$

$$1 \text{ erg} = 10^{-7} \text{ J} \quad \text{cgs units (g,cm,s)}$$

Some exercise....

A car ($m=1.2\text{ t}$) is uniformly accelerating from rest for 12 seconds to reach a velocity of 100 km/h.

- a) Calculate the force necessary for this acceleration.
- b) Calculate the distance run by the car during acceleration.
- c) Calculate the work done by the accelerating force.
- d) Calculate the average power of the car.
- e) Calculate the kinetic energy of the car at the end of the acceleration.

The left ventricle of the heart pumps about 70 g of blood by one contraction into the aorta. This amount of blood reaches the aortic arch that is located approximately 15 cm above the ventricle and has a flow velocity of 30 cm/s.

Calculate:

- a) the work needed to lift the blood,
- b) the work needed to accelerate the blood,
- c) the power of the left ventricle during a contraction that lasts for 0.2 s!

A ball ($m=0.8$ kg) falls to the floor from a height of 2 m and bounces back to a height of 1.2 m.

Calculate the amount of energy lost due to air drag and collision with the ground.

Calculate the amount of energy stored in the Achilles tendon with a spring constant of $3 \cdot 10^5 \text{ N/m}$ that is extended by 2 mm.