DYNAMICS

FORCE

1. Introduction

- Dynamos comes from the Greek word meaning force, dynamics will explain WHY objects move in such a way or change their state of motion and not only describe the motion as in ....
- forces can either change the <u>state of motion</u> of objects or <u>deform</u> them
- force is a <u>scalar/vector</u> quantity – to solve the situation not only the size of the force but also its point of action and direction are important
- forces between two objects can act either when the objects are <u>in contact</u> or <u>influenced by fields</u>

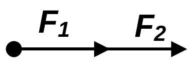
(types of fields: ....)

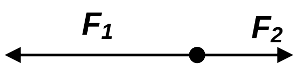
2. Adding and resolving forces

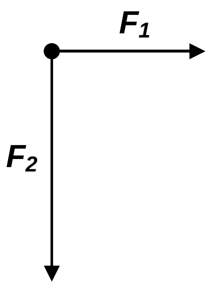
means to replace two (or more) forces by their **resultant**, which must have the same effect as all the forces together

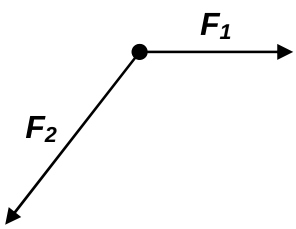
now - forces have the same <u>point of action</u> ≈ as if they act on a mass point

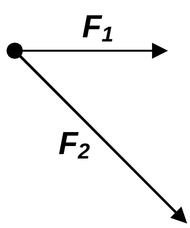
the resultant graphically | its size | its direction











http://www.walter-fendt.de/ph14e/equilibrium.htm

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3. Newton's Laws of Motion

a) Newton's 1st law of motion

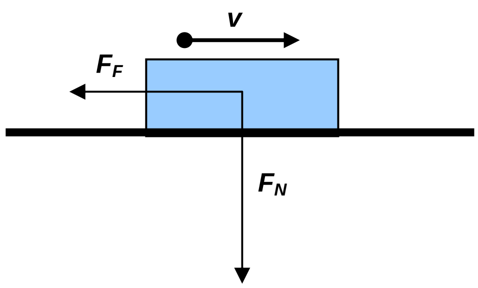
An object at rest stays at rest or an object in motion continues to move in the same direction with the same speed ($\vec{v} = const.$ ***) until it is acted on by a resultant force.***

$$\vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots + \vec{F}_n = \vec{F}_R = 0 \Leftrightarrow \vec{v} = const.$$

Questions:
1. A car moves steadily at 20 m·s^{-1}. Assume the friction force is 1 kN and calculate the force produced by its motor.

FRICTION
is the basic condition and obstacle to motion (explain)
http://phet.colorado.edu/simulations/sims.php?sim=Friction

Friction force is created when one object moves over another. It always acts against the direction of motion and it is based on the irregularities of the surfaces of both objects.



$\boldsymbol{F_F}$ (friction force) depends on: ....

doesn't depend on : ....

$$F_F = f \cdot F_N$$

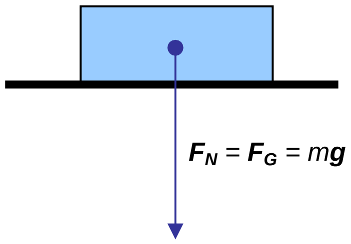
f <u>coefficient of friction</u>

- is a material constant which depends on the quality of BOTH surfaces, but the values written in the book of data are really rough and when we need to know them, it is necessary to measure them (task - design a method)
- f_0 ... limiting c. of friction – when the motion starts from rest
- f ... sliding, dynamic, kinetic c. of friction - when the object is moving, obvious values about 0.3
- $f_0 \rangle f$ ... why? Explain using everyday experience.

$\boldsymbol{F_N}$ <u>normal component of force acting between the objects</u>

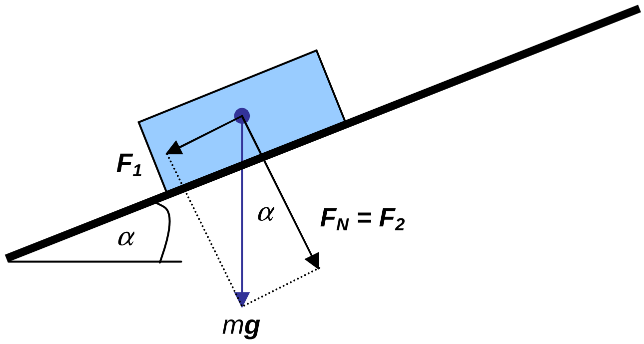
- is obviously connected with the weight of the upper object, but it depends on the angle of the plank

$\alpha = 0$



$F_F = mgf$

$\alpha \neq 0$



$F_N = mg \cos\alpha$

$F_F = mgf \cos\alpha$

http://phet.colorado.edu/simulations/sims.php?sim=The_Ramp

Questions:

2. A steel 10 kg block is pushed to move with constant velocity. Assume the coefficient of friction 0.35 and calculate the force needed to move the block when

a) $\alpha = 0^0$

b) $\alpha = 30^0$

i) up

ii) down

3. State angle between the plank and the ground when the block moves down the slope with constant velocity without any outer force. Take the coefficient of friction 0.4.

4 State the force needed to keep a 80 kg block moving steadily on the horizontal surface when $f = 0.7$.

5 A force of 1.2 N is needed to move a 600 g block steadily (at 10 $m \cdot s^{-1}$) on a horizontal plank. Calculate the coefficient of friction.

L2/79-88

MOMENTUM ($\vec{p}$)

is a vector quantity needed to be defined before we start to work on 2nd NL. Newton invented the quantity when he tried to find something conserved during collisions (mech. energy is NOT – it is partly converted into heat)

$$\vec{p} = m\vec{v}$$

momentum of an object is *m*-times bigger than its velocity and it has the same direction

$$[p] = \mathrm{kg} \cdot \mathrm{m} \cdot \mathrm{s}^{-1}$$

The law of conservation of momentum in an isolated system:

The total momentum in an isolated system remains constant.

$$\sum \vec{p}_{before} = \sum \vec{p}_{after}$$

= when we add momentums (VECTORS) of all the objects in an isolated system BEFORE their collision we must get the same resultant vector as the sum of momentums of the objects AFTER the collision.

This works in 3D as well, but we will only discuss simple situations

Questions:

6. A bullet of mass 2 g leaves the gun of mass 2 kg at 300 m·s^{-1}. Calculate the recoil velocity of the gun and state its direction.

7. a) A railway truck 1 of mass 2×10^4 kg travelling at 0.5 m·s^{-1} collides with another truck 2 of half its mass moving in the same direction with a velocity of 0.4 m·s^{-1}. If the trucks couple automatically on collision, find the common velocity with which they move.
b) Solve a similar situation – the same masses and speeds, just moving against each other.
c) What is the speed after the collision if the objects move at right angles to each other?

*Note: **collision**:*

- ***elastic** – only ideal, mech. energy is conserved*
- ***inelastic** – the objects couple after the collision, mech. energy is not conserved*

http://www.walter-fendt.de/ph14e/collision.htm

b) Newton's 2nd law of motion

The rate of change of momentum of a body is proportional to the resultant force and occurs in the direction of the force.

$$\vec{F}_R = \frac{\Delta\vec{p}}{\Delta t}$$

Note 1: $\vec{F}_R \, \Delta t = \vec{I}$ ... impulse of a force, $[I] = \mathrm{kg \cdot m \cdot s^{-1}}$

Note 2: in many situations mass remains constant, so

$$\vec{F}_R = \frac{\Delta\left(m\vec{v}\right)}{\Delta t} = \frac{m\,\Delta\vec{v}}{\Delta t} = m\,\vec{a}$$

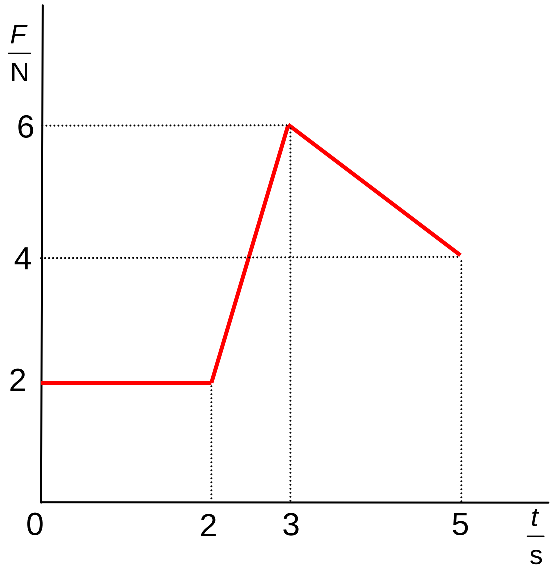
http://www.walter-fendt.de/ph14e/n2law.htm
http://galileo.phys.virginia.edu/classes/109N/more_stuff/Applets/Collision/jarapplet.html

Questions:
8. The motors of a rocket of mass 2×10^6 kg produce an upward force 3.3×10^7 N. What is the acceleration of the rocket?

9. A body of mass 300 g, moving with steady acceleration, has an initial momentum of 220 $\mathrm{kg \cdot m \cdot s^{-1}}$ and after 15 s the momentum is 400 $\mathrm{kg \cdot m \cdot s^{-1}}$. What is the acceleration of the body?

10. A stationary billiard ball has a mass of 200 g. It is hit by a cue that exerts an average force of 50 N during 7 ms. What is the speed of the ball after the impact?

11. Force is applied on a 2 kg originally stationary object as shown on the figure below. Calculate the speed of the object 5 s after the beginning of the collision.



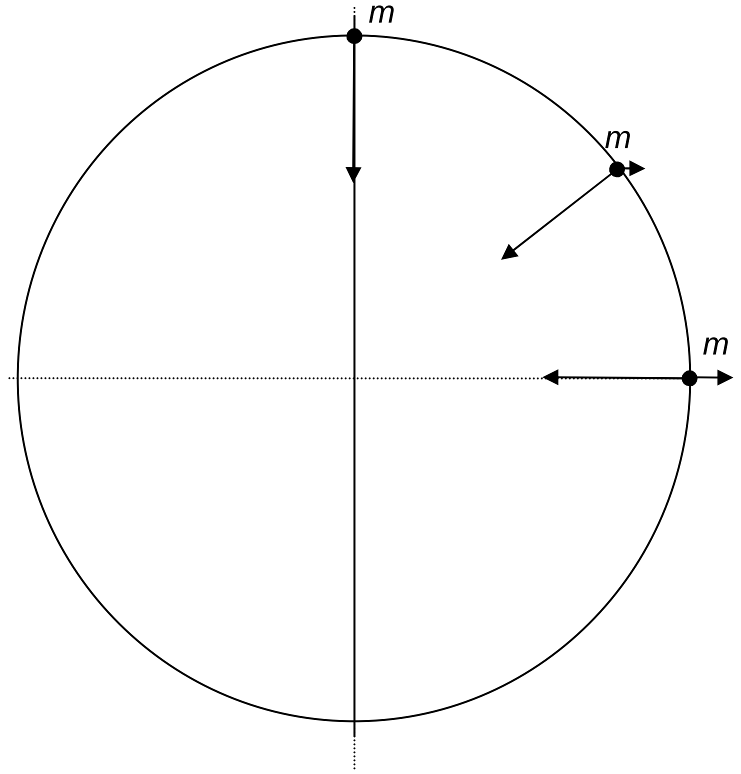
c) Newton's 3rd law of motion

If body A exerts a force on body B, then body B exerts an equal and opposite force on body A.
These forces must simultaneously appear and disappear. They don't cancel each other, because they act on different objects.

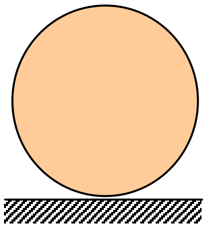
L2/89-104, X105-110, 111-138

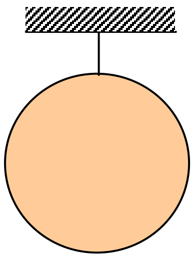
TÍHA a TÍHOVÁ SÍLA
jsou termíny, které se v angličtině jako speciální pojmy neuvádějí. Řeší se jako gravitační síla ve zvláštní situaci.

Tíhová síla je síla, která přitahuje těleso k Zemi. Je výslednicí síly gravitační a odstředivé, směr přesně do středu Země má pouze na rovníku a na pólech. Její působiště je v těžišti tělesa.



Tíha je síla, kterou těleso v tíhovém poli země tlačí na podložku nebo táhne za závěs. Její působiště je v bodě, kde těleso táhne nebo tlačí. Zakresli tíhu a tíhovou sílu:





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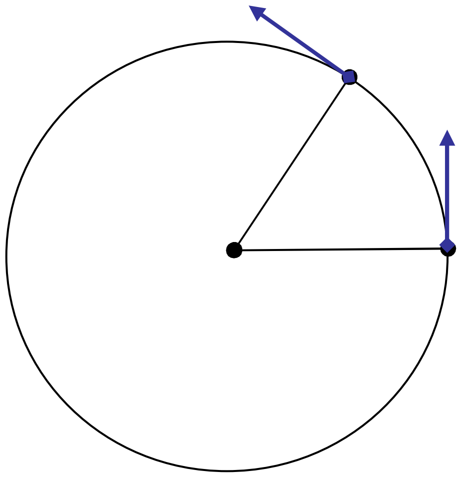
4. Dynamics of steady circular motion



$v = const$ but $\vec{v} \neq const$

$\boldsymbol{F_C}$ ... centripetal force
$\boldsymbol{a_C}$ ... centripetal acceleration

- as the trajectory is not a straight line, there is a resultant force (2^{nd} NL)
- as the resultant is perpendicular to the direction of velocity, it changes only its direction and not the size

$$F_C = ma_C$$

$$a_C = \omega^2 r = \frac{v^2}{r}$$

http://phet.colorado.edu/simulations/sims.php?sim=Ladybug_Motion_2D

Questions:
12. A pulsar of diameter 15 km rotates at a frequency of 8 Hz. Calculate the speed and the centripetal acceleration of a point on the equatorial diameter of the pulsar.

13. A vehicle has tyres of diameter 0.6 m. Work out the angular speed and the centripetal acceleration of a point on the tyre tread when the car is travelling at 20 $m \cdot s^{-1}$.

L2/146-152, X153-160

5. Inertial frame of reference

In an inertial frame of reference isolated objects obey 1^{st} NL – stay at rest or move with constant velocity. This frame of reference cannot be accelerated. When the frame is not inertial, e.g. accelerated, forces can act on objects even when they are not in contact with other objects.

A ball is placed on the floor in a train. Discuss its motion relative to the train when the train moves with constant velocity, accelerates or decelerates.

Non-inertial frame of reference

moves relative to the inertial one with acceleration.

It can provide the following types of motion ....

1st and 3rd NL do not work in these frames of reference (discuss on examples).

Force of inertia is applied to objects in non-inertial frames of reference.

$$\vec{F}_s = -m \cdot \vec{a}_s$$

Questions:

14. Discuss the motion of a ball and the resultant force applied to it when it is placed
    a) in a train moving with a constant velocity, accelerated, decelerated
    b) in a lift moving up/down with constant velocity, accelerating when moving up/down, decelerating when moving up/down

15. Discuss the circular motion of a bumble-bee toy whirled round on a string
    a) in the frame connected with the Earth
    b) in the frame connected with the bumble-bee

L2/139-145

Answers:

1. 1 kN
2. 35 N, 80 N, -20 N
3. 21.8°
4. 560 N
5. 0.2
6. $0.3\ m \cdot s^{-1}$
7. $0.47\ m \cdot s^{-1}$, $0.2\ m \cdot s^{-1}$, $0.36\ m \cdot s^{-1}$
8. $6.5\ m \cdot s^{-2}$
9. $40\ m \cdot s^{-2}$
10. $1.75\ m \cdot s^{-1}$
11. $9\ m \cdot s^{-1}$
12. $377\ km \cdot s^{-1}$, $19 \times 10^6\ m \cdot s^{-2}$
13. $67\ rad \cdot s^{-1}$, $1333\ m \cdot s^{-2}$