1) Interrogation orale d'un élève sur la partie : <u>the gravity field</u>, traitée au cours précédent :

Prévoir de faire participer les autres élèves au besoin.

- Last time, we spoke about fields in physics; could you give examples of field?
  Magnetic field, electric field, gravitational field

- What is a field?
  This is a space area (zone) where something undergoes a force

- What is responsible for a magnetic field?
  Permanent magnets or currents

- For an electric field?
  Electric charges

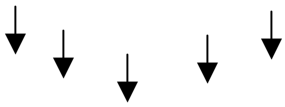
- For a gravitational field?
  Masses

- How is a field usually represented in physics?
  By arrows (vectors)

- Picture the gravity field on the blackboard

- Something is missing, can you help him (her)…

- Is there only one point in space…?



- What does the same length mean?
  It means that the field is the same everywhere (has the same size)

- How do we detect the gravity field?
  When we drop something, it falls vertically

- What are the units for g?
  m/s^2 or N/kg

- What is the unit m/s^2 usually used for?
  It is used for acceleration

- Which acceleration does it correspond to?
  It corresponds to the gravity acceleration (or acceleration of free fall)

And the unit N/kg corresponds to the gravity field…

- What was Newton's hypothesis concerning the free fall acceleration and the gravity field?

Or

- What was Newton's hypothesis concerning weight and gravitational force?
  He suggested they were equal.

Well, the aim of today's lesson is to understand how he came to this idea and how he interpreted the motion of the Moon around the Earth.

B) Forces change velocities

2) Read the second part by yourself (from “Newton explains that…” to “velocity”). Underline **one key sentence** in each paragraph, pointing out **the effect of forces on velocities**. Prepare yourself to justify.

§ 1: from “Newton explains…” to “sometimes both”
§ 2: from “This is connected…” to “relative”
§ 3: from “This is a far cry…” to “their velocity”

Laisser du temps, interroger nominativement plusieurs élèves sur le même paragraphe.
Réponses possibles : Faire noter les réponses sur le cahier.

§ 1: “Newton explains that whenever a velocity is changed, a force must be involved” or “According to Newton, forces change velocities-sometimes in magnitude (speed), sometimes in direction, sometimes both”

Thanks to the change in velocity, either in direction or in magnitude, we can recognize the existence of a force; the change in velocity is an evidence for a force, even if we cannot see it.

§ 2: “No force, no change in velocity” or “Movement itself needs no force”

How do you react to this statement?

It is shocking because in usual life, we need large forces to let things move. So it is incredible that motion should exist without force.

§ 3: They (the planets) just keep going unless a force changes their velocity.

In looking at the sky, we know that a force should exist. Without it, stars would not go in circular path but straight on.

3) To keep on studying the **effect of forces on velocities**, we can look at the pictures besides.

- What are the four examples of motion in **fig 3**?

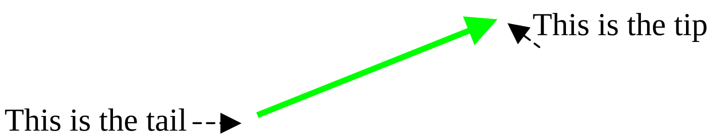
Ball lobbed in tennis, footballer deflecting the ball, comet approaching the Sun, Moon orbiting the Earth.

- What do the arrows in the pictures stand for?

They stand for velocities or changes in velocity.

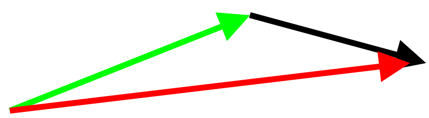
- Do you remember what the **tip-to-tail rule** consists in?…

Consider a vector:



To add two vectors, you must stick the **tip of the first** to **the tail of the second one**

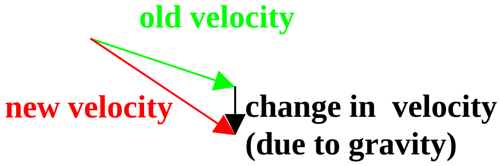
The resultant is in red:



For velocities, it is the same:

Old velocity + change in velocity = new velocity

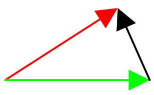
Take the example of the ball lobbed in tennis:



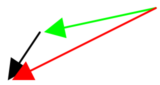
4) Label the other examples the same way I did:

Old velocity in green
Change in velocity in black, precise what the change is due to
New velocity in red

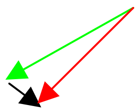
Interroger plusieurs élèves au tableau pour corriger les constructions



change due to the footballer's action



change due to the pull of the Sun on the comet



change due to the pull of the Earth on the Moon

5) In the last example (Moon orbiting the Earth), velocity changes and speed stays the same.

But what is the link between change in velocity and force?

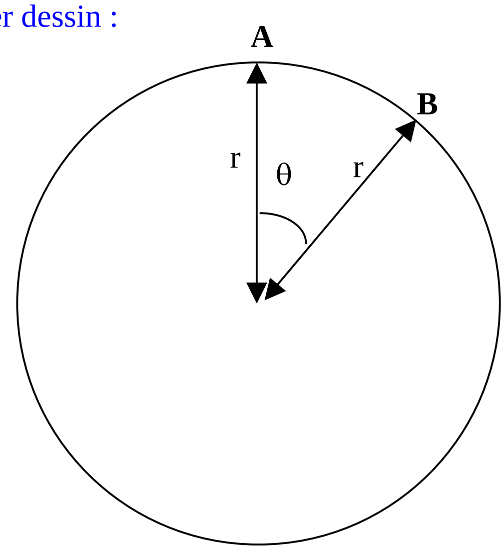
$$\frac{\text{change in velocity}}{\text{time}} = \text{acceleration} \qquad \text{and} \qquad \text{force} = \text{mass} \times \text{acceleration}$$

C) How can we work out acceleration, when only velocity changes and not speed?

5 a) I give you a drawing with some keys.
The class will be split in two parts: you have two sorts of drawing. Each of you must write instructions to your school friend to make him (her) draw it.

La classe est séparée en deux, chaque partie a un dessin à décrire aux autres…

Premier dessin :



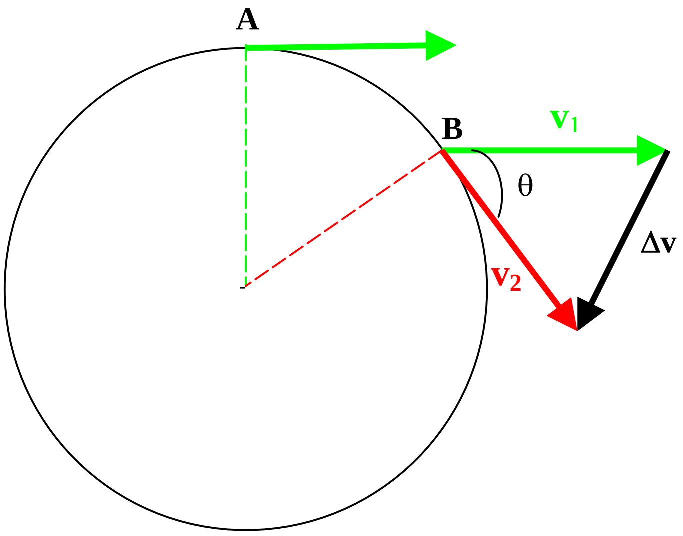
TEAM A

Circular orbit

Radius r

During time Δt, radius turns through θ

deuxième dessin : **TEAM B**



Constant speed v

Old velocity v_1

New velocity v_2

Change in velocity Δv

During time Δt, velocity turns through θ

Interrogation orale : un membre de l'équipe A décrit le dessin à un membre de l'équipe B, puis on permute les rôles. Quand les deux dessins sont au tableau, on pose des questions à l'ensemble de la classe.

5 b) Now, copy both drawings on the empty fig 4.

5 c) What is the relation between AB, r and θ (rad) in the first drawing? $\theta\ (\text{rad}) = \frac{AB}{r}$ (1)

5 d) What is the relation between change in velocity Δv, speed v and θ (rad) in the second drawing?

$\theta\ (\text{rad}) = \frac{\Delta v}{v}$ (2)

5 e) At constant speed, what is the relation between AB, v and Δt? Rearrange in (1).

5 f) Thanks to (1) and (2), express the acceleration.

6) Now the final question is:

D) How did Newton explain the motion of the Moon around the Earth?

First, he used a geometrical argument developed in the first paragraph:

6a) Read the first paragraph concerning Newton's gravitational law (from "Newton had thought…" to "and so on") and rewrite the underlined phrases in mathematical language.
Laisser du temps ; Donner le premier exemple.

An inverse square law involves a quantity (a force for example) which is inversely proportional to the square of the radius, so we would write $F \propto 1/r^2$

The square of the distance = d^2
One quarter = ¼
Distance doubles = d x 2
One ninth = 1/9
Distance trebles = d x 3

6b) To illustrate the properties of the gravitational law we can use the fig 5. In this figure, quote the picture:

- that shows the inverse square law in geometry : *(c)*
- that shows the inverse square law in calculus : *(b)*
- that shows all particles attract each other: *(a)*

7) Now we have all the data Newton used to explain the motion of the Moon around the Earth. Look at fig 6:
Laisser du temps

First picture:

- What does the drawing stand for? *The trajectory of the Moon around the Earth.*

- What does the time correspond to? *The period of revolution.*

- What does the distance correspond to? *The length of the orbit*.

- How do we calculate the speed? *By dividing the distance covered on the orbit by the period.*

- What is the result? *One thousand twenty metre per second.*

- How do we calculate the acceleration? *By dividing the squared speed by the radius of the orbit.*

- What is the result? Transform it into powers of ten? *Two point seven times ten to the power of minus three metres per second squared.*

Second picture:

- What is the radius of the Moon's orbit? *Three hundred and eighty four thousand kilometres.*

- What is the value of the Earth's radius? *Six thousand four hundred kilometres.*

- What is the ratio between them? *One over sixty*.

- How did Newton calculate the gravity acceleration at Moon's orbit? *By dividing by sixty squared.*

- Why? *Because gravitational law is an inverse square law*.

- Does it fit the previous result? *Yes*

- So what conclusion can we draw? *The acceleration of the Moon is due to gravity, the same as the one that makes things fall on the Earth.*

- Which sentence in the second paragraph of Newton's gravitational law (from "While" sitting in an orchard… to "a Moon") confirms this conclusion. "*Movement on Earth and motion in the heavens became all the same thing*".
- Underline it.

As a conclusion: exercise…