Forces

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Learning Outcome

I highly recommend you to finish this checklist to determine whether you've achieved the learning objectives.

- [ ] Define and distinguish different types of forces
- [ ] Use a vector triangle to represent coplanar forces in equilibrium
- [ ] Add two or more coplanar forces
- [ ] Resolve a force into perpendicular components
- [ ] Recognise that mass is a property of an object that resists change in motion
- [ ] Recall that the weight of a body is equal to the product of its mass and the acceleration of free fall
- [ ] Represent the weight of a body as acting at a single point known as its centre of gravity

Leadin

The Force from the movie "Star War" is not the force that physics world would discuss

Figure 1: Yoda

Forces

How to define force? What is Force? If you want to dig more, these questions can be of great concern in a much more precise sense. But generally speaking, forces could be defined as

Summary

Forces are the Interactions between Objects

Types of Forces

The most common forces are classified into the following categories[1].

- Pushes and pulls, the most common forces that human or engine can exert on other objects.
- Weight, or force of gravity.
- Friction, this force arises when two surfaces rub over one another.
- Drag, which is similar to frcition, but arise when object moving through *fluids*[2]
- Upthrust, or Bouyance, arises from the *difference in pressure* that a fluid exerts on an object. This is the reason why boat or ballon can float.
- Normal Contact force, is one type of force which can support the objects to fight against the weight. It is always perpendicular to the surface of contact[3].
- Tension, occurs in the string or rope when you pull the string or rope. Remeber that tension occurs everywhere in the tensile objects and it always tends to contract the objects.

Resultant Force-Combining Forces

If two or more force are acting on the same object, due to the fact that forces are vectors, those forces can be added together in order to use just one *resultant force* to substitue the original forces. The resultant force will actually have the same effect on the object as the two or more forces. This is the critical principle to dynamics[4].

[1] We will talk about four fundamental forces/interaction later

[2] def:

[3] that's what normal means

[4] Analysing all forces and determine the resultant force is quite important to dynamics, and such content will be discussed later

Task

Draw the resultant forces of F_1 and F_2, you can use either *triangle rule* or *parallelogram rule*.

In the *free body diagram*[5] of the car, we could work out their combined effect on the car. And hence determine whether the car will accelerate or decelerates.

[5] def: a diagram which shows all the forces acting on the object

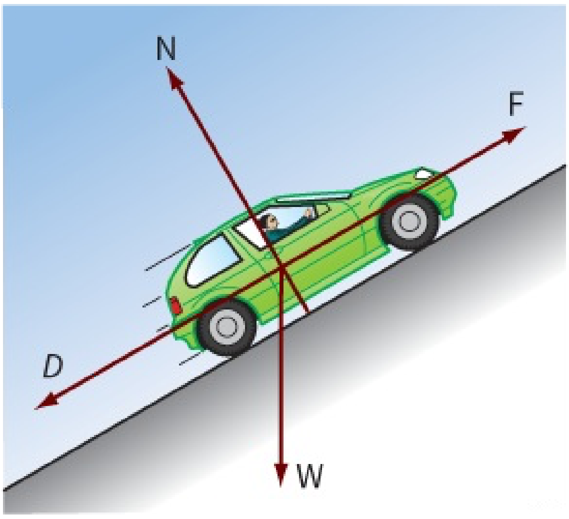

Figure 2: Four forces act on this car as it moves uphill.

Coplanar Force Triangle

Recall what you've learned about the vector nature, as well as the addition rule, of forces. it is not difficult to learn this keypoint.

Basically, if three *coplanar* forces acting on the same object so that the object remain in *equilibrium*[6]. Then the three forces will definitely form a **triangle** in which the ends and starts connect from one another.

[6] def: An object in equilibrium will keep stationary or uniform motion; The dynamics reason for equilibrium is that the **resultant force** on that object is zero

Task

Try to explain why three forces will form such triangle

In the same graph, label a third force F_3 which will form a force triangle with F_1 and F_2, think about the relationship between F_3 and $F_1 + F_2$.

Sometimes, the three forces may be arranged so that it will be starting from the samepoint, such as the *centre of mass* of the object, illustrated in figure **??**.

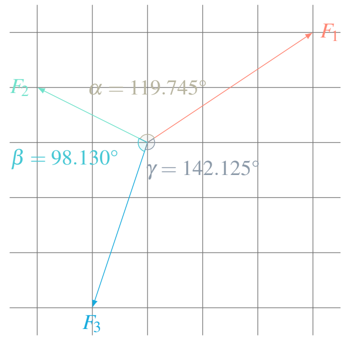

Figure 3: three forces from the same point

Task

Using parallel movement of forces, show that $F_1 + F_2 + F_3 = 0$

Extended Task:
Measure the length of F_1, F_2 and F_3, and hence calculate the value of $F_1/\sin\beta$, $F_2/\sin\gamma$, and $F_3/\sin\alpha$. What did you find?

Decompose of Forces

Have you ever got a feeling that, always using the addition graph to find the resultant forces is not mathematically elegant and fast enough. So decomposition of vectors has been introduced here again.

Ususally, vectors are decomposed into *horizontal and vertical components*. And then, the addtion would be a piece of cake. Try to decompose F_1, F_2, F_3 into horizontal vectors and label the angles the force makes with positive horizontal direction respectively, and calculate the total horizontal and vertical components.

Mass & Weight

Do you really understand what the mass represent? In the junior high schol level, you might know that mass is the physical quantity which measures how many substance in an object. For example, 1 kg of steel has more substance than 0.9 kg of steel. However, in this section, you will view mass from a brand new perspective.

Inertia

Galileo has proposed a mind experiment shown in figure **??** in which a ball is released at certain height in an inclined plane, the ball always achieve the same height no matter the ramp's length. Thus, if the track is flat, the ball seems to move forever, and this property is called *inertia*

Definition 0.1 *The tendency of a moving object to **carry on moving** or the tendency of a stationary object to remain rest, is sometimes known as inertia. Alternatively, inertia is the property that object resist change in its motion state.*

And think a train compared with a tennis ball, which one is more likely to move if resistance is applied. And which one tends to remain rest if force is applied? Both answers are the train, because it tends to have much larger mass than the tennis ball, thus larger inertia.

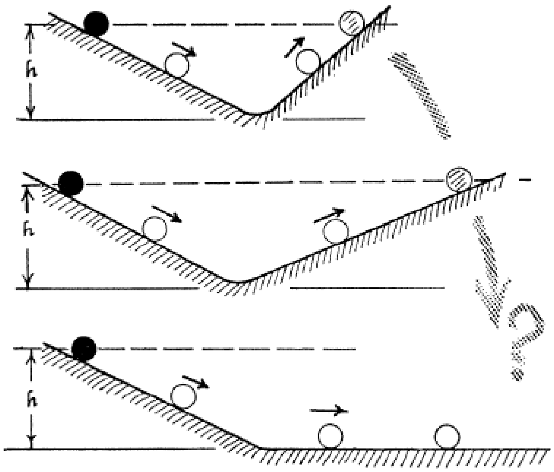

Figure 4: Galileo's Mind Experiment

Summary

Mass is the measure of inertia, the larger the mass, the larger the inertia

Weight

Weight is the force that an astronomical body, like a planet or star, exert on the object on the surface of it. The direction of the weight is always to the center of the celestial body.

And we found that the weight of an object is always *directly proportional* to the mass of the object, the coefficient of proportionality is g, the acceleration of free fall on the surface of the planet. Thus

$$W = mg \tag{1}$$

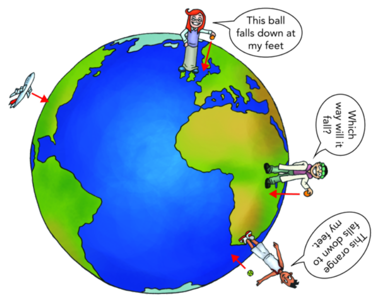

Figure 5: The direction of weight is always to the centre

Try to explain the meaning of the symbols. And state the units for each quantity.

As discussed above, the acceleration due to gravity on Earth is $g_{\text{Earth}} = 9.81\,\text{m}\,\text{s}^{-2}$. While the acceleration due to gravity on Moon is approximately $1/6$ of that. The value is $g_{\text{Moon}} = 1.62\,\text{m}\,\text{s}^{-2}$. That means you can jump six times taller on the moon than what you can do on Earth, you'll definitely beat any Olympic champions ever.

Despite the weight changes on the Moon, the mass never change. This is a key difference between mass and weight.

Centre of Gravity

When we talk about the weight, actually every part of our body - arms, legs, head - experiences the weight of gravity. However, it is much simpler to picture the overall effect of gravity as acting at a single point. And that point is called *centre of gravity* [7].

[7] centre of mass is a similar concept but a little bit different

Figure 6: An astronaut can jump easily on the Moon

Definition 0.2 *Centre of Gravity is the point where all the weight of the object may be considered to act.*

Using CG can make things much more simpler, we can ignore the size, the shape, anything else but only the weight, the object can be treated as a single point. Sometimes it is also referred to as *mass point model*

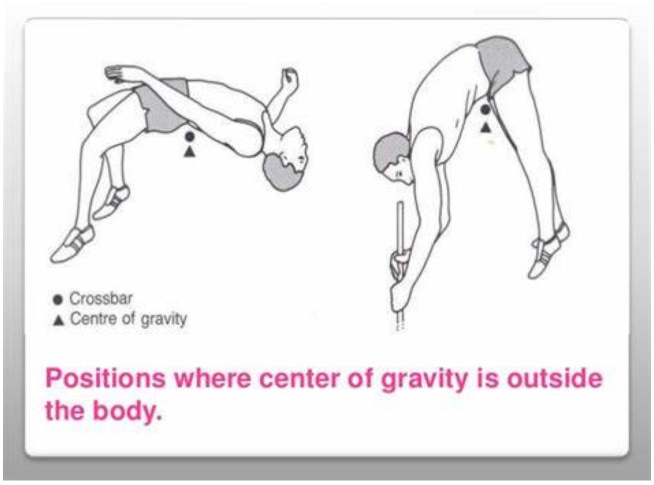

Figure 8: Sometimes, the CG can be outside human's body

Figure 7: This toy is popular in my childhood, where should the CG be?

If an object is *uniform in density* and in regular shape, such as an rectangle, circle, isoceles triangle in 2D, sphere, cube in 3D, both the CG and Centre of Mass lies in the geometric centre. However, life is so hard, nearly real life object is not in standard shape, such as human body. How could we find the CG? A techinique called '*suspension*' is employed.

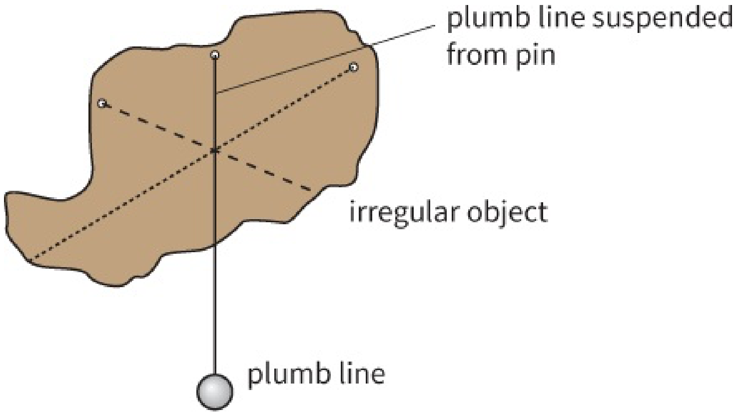

Figure 9: For any irregular static object, it is a simple way to determine the CG