

第二課

力和運動 Force and motion

全年班

力的性質 Properties of forces

- 可分為接觸力和非接觸力。
Forces can be categorised into contact forces and non-contact forces.
 - ▶ 接觸力：包括張力、法向力、摩擦力、流體阻力；
Contact forces: includes tensions, normal forces, frictions and fluid resistances;
 - ▶ 接觸力：包括張力、法向力、摩擦力、流體阻力；
Contact forces: includes tensions, normal forces, frictions and fluid resistances;
 - ▶ 非接觸力：包括重量、電力、磁力。
non-contact forces: includes gravitational force, electric forces, and magnetic forces.
- 在國際單位制中，力的單位是牛頓，符號為 **N**。
The S.I. unit of forces is Newton, which can be written as **N**.

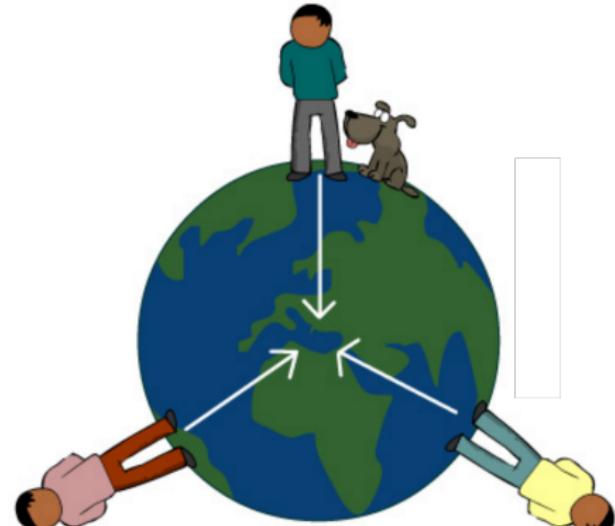
力的性質 Properties of forces

- 力是矢量，有量值和方向。向某方向作用的力，可用箭號來表示，箭號的方向和長度分別顯示力的方向和量值。

Forces are vectors consisting of magnitudes and directions and represented by arrows. The directions and magnitudes of the arrows represent that of the forces.

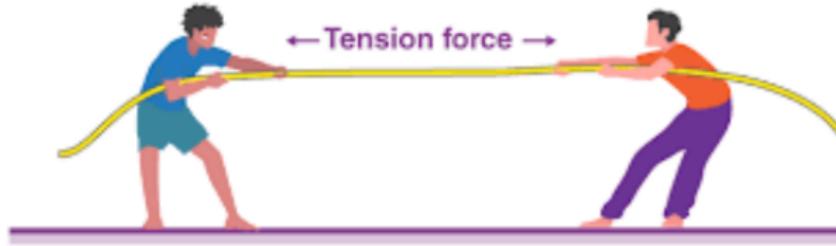
重量 (W) Weight (W)

- 地球作用於物體的拉力。
Pulling forces acting on objects by the Earth.
- 方向指向地球的中心。
Its direction is towards the center of Earth.
- $W=mg$, g = 重力加速度 acceleration due to gravity



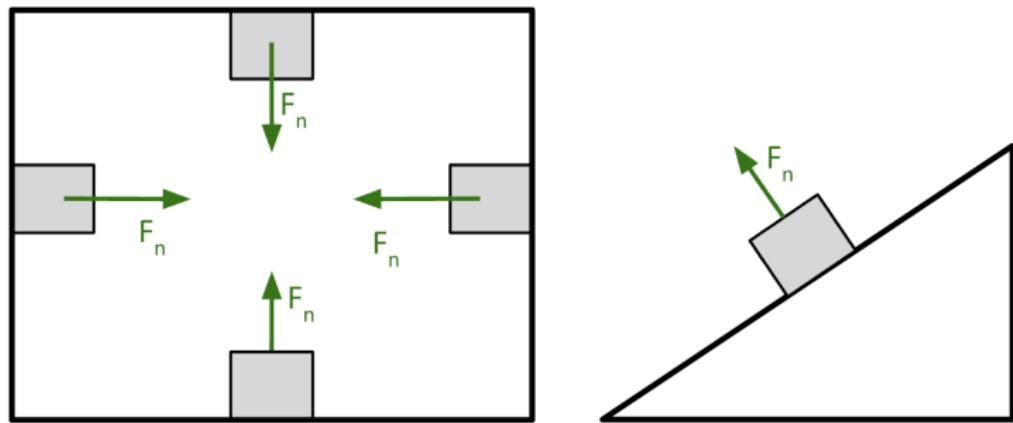
張力 (T) Tension(T)

- 繩子拉緊時產生的力。
Forces generated when a string is pulled tightly.
- 在無質量的繩子裏，繩子每一點的張力量值都是相同的。
In a massless rope, the tension at every point of the rope is the same.



法向力 (N 或 R) Normal force (N or R)

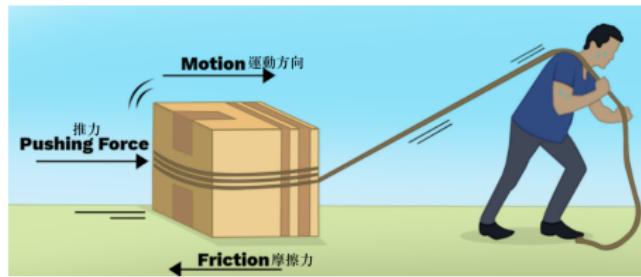
- 兩個物件的表面接觸所產生的力。
Forces generated between two contact forces.
- 力和表面必定互相垂直。
Force and surface are always perpendicular to each other.



阻力 (f) Opposing force (f)

- 例子：Examples:

- 固體之間的摩擦力。
Frictional forces between solids.
- 空氣阻力。
Air resistance.
- 液體阻力。
Fluid resistance.
- 剎制力。
Braking force.



阻力 Opposing force

- 防止兩個接觸面發生相對運動所產生的力。

The force that prevents relative motion between two contacting surfaces is called frictional force.

- 存在一個最大量值。

There exists a maximum magnitude.

- ▶ 阻力隨相對運動程度的增加而增加。沒有相對運動就沒有阻力。

Opposing force increases with the degree of relative motion.

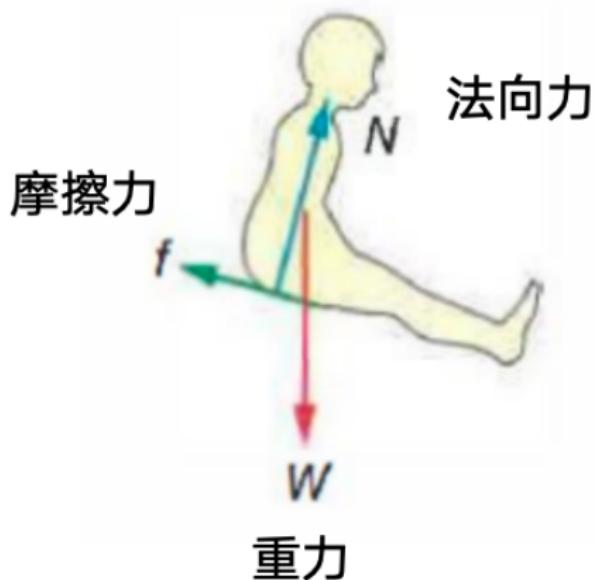
Without relative motion, there is no resistance.

- ▶ 當阻力超過最大值時，阻力不會再增加。

When the resistance exceeds the maximum value, the resistance will not increase further.

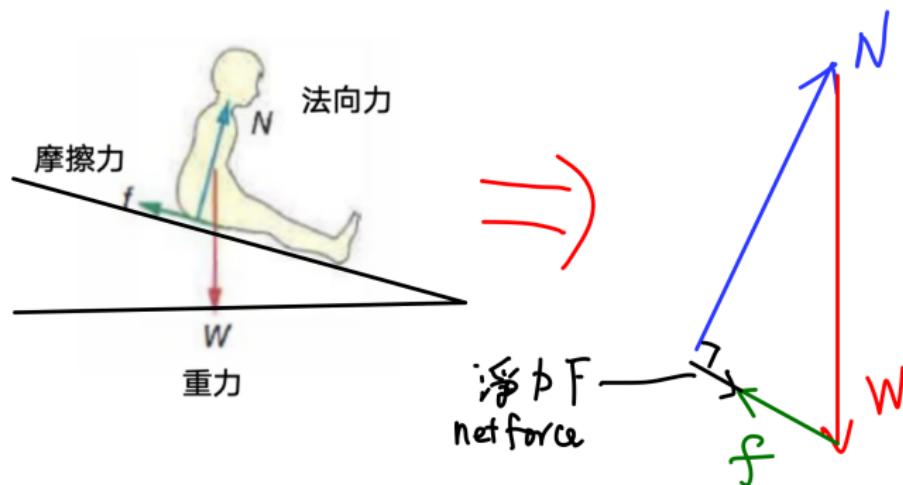
自由體圖/隔離體圖 Free body diagram

- 顯示所有作用於物體的力。Indicates all forces acting on a body.

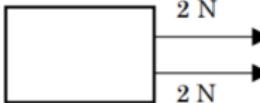
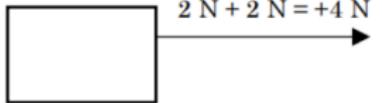
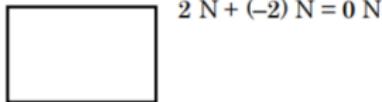
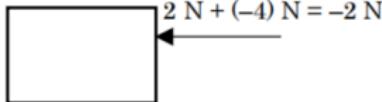


淨力/合力 Net force/Resultant force

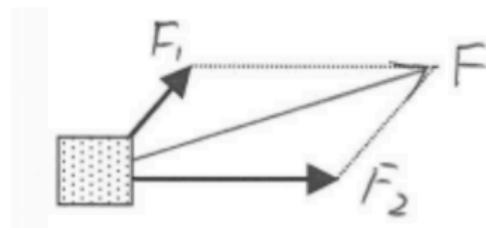
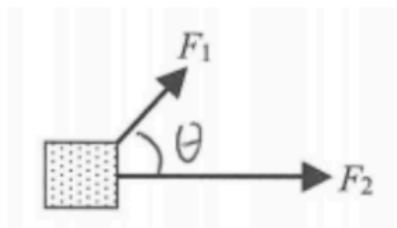
- 施加於物體的所有力的向量和。
Vector sum of all forces of an object.



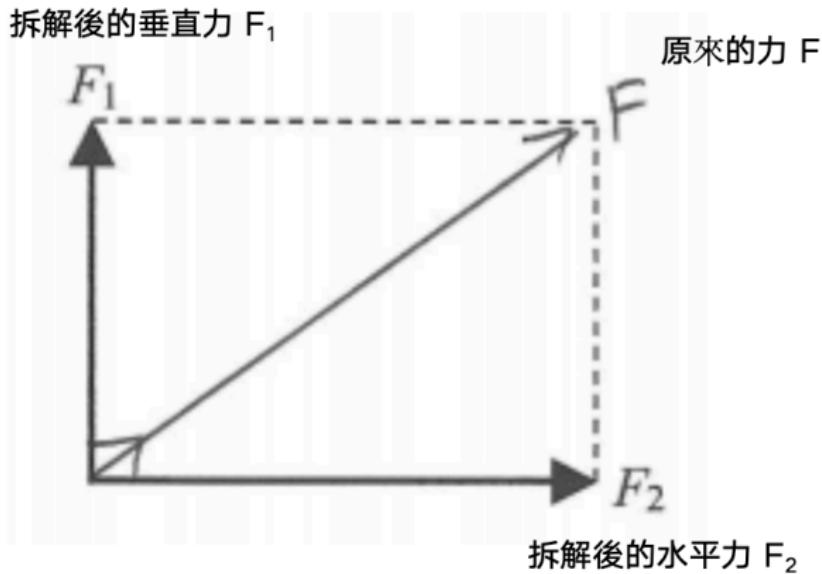
淨力/合力 Net force/Resultant force

力 Force	淨力 Net force
	
	 $2\text{ N} + (-2)\text{ N} = 0\text{ N}$
	

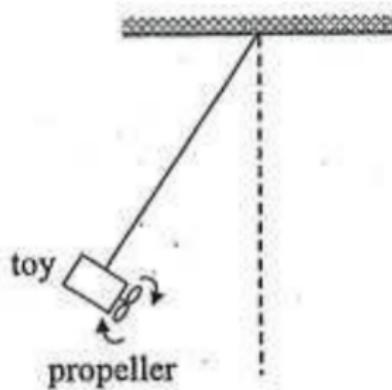
淨力/合力 Net force/Resultant force



力的拆解方法 Force breaking into components



例題 Example



這個玩具裝了一個推進器和現在在靜止狀態。畫出這個玩具的自由體圖。

This toy is equipped with a propeller and is currently at rest. Draw the free-body diagram of this toy.

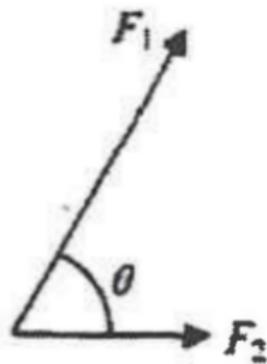
例題 Example

如圖所示，兩個量使固定的力 F_1 及 F_2 作用於同一點，當 F_1 與 F_2 的夾角 θ 由 0° 增加至 180° ，求合力的量值的變化。

- (a) 增加 (b) 減少 (c) 先增加後減少 (d) 先減少後增加

As shown in the diagram, two forces, F_1 and F_2 , are applied to the same point. When the angle θ between F_1 and F_2 increases from 0° to 180° , what is the change of the magnitude of the resultant force?

- (a) increases (b) decreases (c) increases then decreases (d) decreases then increases.



牛頓力學定律

Newton's Three
Laws of motion



Issac Newton 1642 – 1627

牛頓第一定律和慣性 Newton's first law and inertia

牛頓第一定律 Newton's first law

除非受到淨力作用，否則所有物體都會保持靜止狀態或勻速直線運動狀態。

Unless there is a net force, the object stays at rest or moves uniformly.

慣性 inertia

慣性是物體保持靜止或以均勻速度運動的趨勢。

Inertia is the tendency of a body to remain at rest or moving with uniform velocity.

牛頓第一定律和慣性 Newton's first law and inertia

- 慣性使物體繼續以勻速移動。
Objects keeps its uniform speed because of inertia.



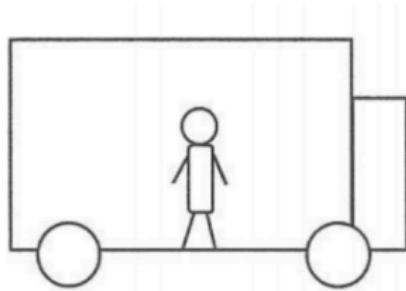
安全帶的應用 Application of seat belts

- 當移動中的車子突然停車，因為慣性乘客會繼續前進。
When a moving vehicle suddenly stops, due to inertia, passengers will continue to move forward.
- 安全帶可以防止乘客被拋出車外。
Seat belts are designed to prevent passengers from being thrown out of the vehicle.



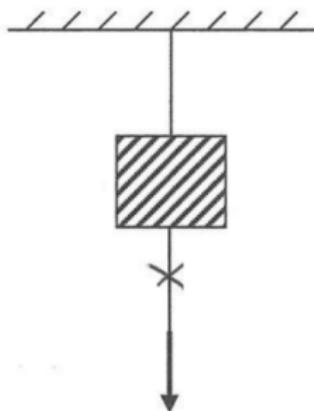
牛頓第一定律和慣性 Newton's first law and inertia

- 慣性使物體繼續靜止。
A body will remain at rest due to its inertia



牛頓第一定律和慣性 Newton's first law and inertia

- 惯性使物體繼續靜止。
A body will remain at rest due to its inertia.
- 慢拉線 \Rightarrow 上面先斷
string is pulled slowly \Rightarrow upper string breaks.
 - ▶ 上面部分承受更大的張力。
upper string breaks because it has greater tension.
- 快拉線 \Rightarrow 下面先斷
string is pulled quickly \Rightarrow lower string breaks.
 - ▶ 物件傾向保持靜止狀態。
because the block tends to remain at rest.



牛頓第二定律 Newton's second law

牛頓第二定律 Newton's second law

$$\vec{F} = m\vec{a} \quad (1)$$

- 物件受到的淨力 F 與物件的質量 m 及加速度 a 成正比，且淨力和加速度方向相同，且量值滿足 $F = ma$ 。

An object of mass m accelerates at a when it is experiencing a net force F , then the directions of F and a are the same, and their magnitudes fulfil $F = ma$.

- 淨力、質量和加速度分別採用 S.I. 單位牛頓 (N)、千克 (kg) 和米每平方秒 (m s^{-2}) 。

the net force, mass and acceleration are in the S.I. units, Newton (N), kilograms (kg) and meters per second squared (m s^{-2}) respectively.

例題 Example

一塊起始靜止的方塊放在光滑的桌子上，被一個水平的恆定力 F 推動。利用牛頓運動定律，解釋為什麼這個方塊應該開始移動。

A block which is initially at rest and placed on a smooth table is being pushed by a horizontal constant force F . Using Newton's Law of Motion, explain why the block should start to move.

解 施加在方塊上垂直方向的合力（重力和法向反作用力）是平衡的。
水平方向有非零的淨力 F 作用於方塊上。
根據牛頓第二定律，方塊應該會有與力同方向的加速度。

Ans The vertical forces (weight and normal reaction) are balanced, While there is an unbalanced horizontal resultant force F acting on the block.
By Newton's 2nd law, the block should have acceleration with same direction to the force.

例題 Example

一個球質量為 4 kg ，它被輕推了一下後，以速率 2 m s^{-1} 運動。 10 s 後，它停了下來。

The mass of a ball is 4 kg , after being pushed, it moves at 2 m s^{-1} . After moving for 10 s , it stops.

(a) 求球與地面間的摩擦力。

Find the friction between the ball and the ground.

例題 Example

一個球質量為 4 kg ，它被輕推了一下後，以速率 2 m s^{-1} 運動。 10 s 後，它停了下來。

The mass of a ball is 4 kg , after being pushed, it moves at 2 m s^{-1} . After moving for 10 s , it stops.

(b) 如果摩擦力減半而其他因素不變，球移動的距離是多少？

If the friction reduces by half and the other factors stay unchanged, what is the distance covered by the ball?

例題 Example

一個球質量為 4 kg ，它被輕推了一下後，以速率 2 m s^{-1} 運動。 10 s 後，它停了下來。

The mass of a ball is 4 kg , after being pushed, it moves at 2 m s^{-1} . After moving for 10 s , it stops.

(c) 如果摩擦力加倍而其他因素不變，球移動的時間是？

If the friction doubles and other factors stay unchanged, what is the moving time of the ball?

例題 Example

一個男孩的質量是 30 kg 。他以 5 m s^{-1} 垂直到達水而且他最深下降至 2 m 。求水對男孩施力的量值。

The mass of a boy is 30 kg . He reaches the water surface at 5 m s^{-1} vertically downward and he reaches 2 m of depth at most. Find the magnitude of the force acted on the boy by water.

拆力相關題目 Problems about breaking forces

- 把力分解成水平和垂直方向。

Breaking down the force into vertical and horizontal components.

- ▶ 然後把該方向的所有力放一邊， ma 放另一邊。

Then, all the forces in that direction are placed on one side, while ma (mass times acceleration) is placed on the other side.

- ▶ 如果是靜止/勻速，一邊方向的所有力 = 另一邊方向的所有力。

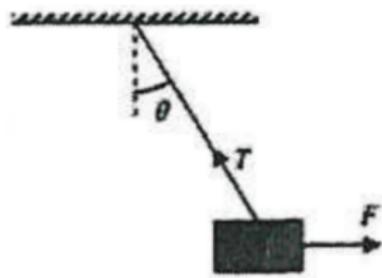
If the object is at rest or moving at a constant velocity, the sum of all forces in one direction is equal to the sum of all forces in the opposite direction.

- 斜坡問題：Problems related to a slope:

- ▶ 把力分解成沿斜坡，和垂直於斜坡。

Breaking down the force into direction along the plane and perpendicular to the plane.

例題 Example



以 F 和 θ 表示方塊的重量。

Find the weight of the block in terms of F and θ .

例題 Example

揚浩將手推車推上斜坡。他施於手推車的力平行於斜坡，量值為 200 N。斜坡與水平線的夾角為 10° 。手推車連貨物的質量為 50 kg，斜坡施於手推車的摩擦力為 80 N。

Y.H. pushes a trolley up along a slope. The force that he acts on the trolley is parallel to the slope, and the magnitude is 200 N. The inclination of the slope is 10° . The total mass of the trolley and the goods inside is 50 kg, the friction between the slope and the trolley is 80 N.

(a) 斜坡施於手推車的法向力，量值是多少？

What is the magnitude of the normal force acting on the trolley by the slope?

例題 Example

揚浩將手推車推上斜坡。他施於手推車的力平行於斜坡，量值為 200 N。斜坡與水平線的夾角為 10° 。手推車連貨物的質量為 50 kg，斜坡施於手推車的摩擦力為 80 N。

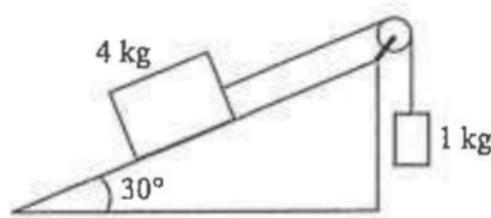
Y.H. pushes a trolley up along a slope. The force that he acts on the trolley is parallel to the slope, and the magnitude is 200 N. The inclination of the slope is 10° . The total mass of the trolley and the goods inside is 50 kg, the friction between the slope and the trolley is 80 N.

(b) 求手推車的加速度量值。

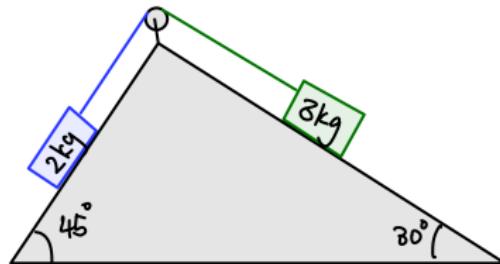
Calculate the magnitude of the acceleration of the trolley.

滑輪問題 Pulley problems

- **輕質不可延伸的繩子**：繩子上每一個點的張力皆為零。
A light and **inextensible** string: The tension at every point on the string is **zero**.
- **光滑滑輪**：滑輪兩邊的張力量值**相等**。
Smooth pulley: magnitudes of tension on both sides of pulley are equal.



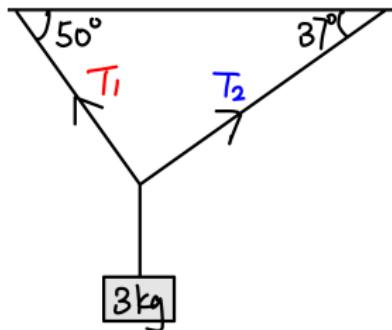
例題 Example



所有表面光滑，取重力加速度 $g = 9.81 \text{ m s}^{-2}$ 。求繩子的張力。

All surfaces are smooth, and the gravitational acceleration is given by $g = 9.81 \text{ m s}^{-2}$. Find the tension in the string.

例題 Example



取重力加速度 $g = 9.81 \text{ m s}^{-2}$ 。求繩子的張力 T_1 和 T_2 。
the acceleration due to gravity is given by $g = 9.81 \text{ m s}^{-2}$. Find the tensions T_1 , T_2 in the string.

升降機問題 Elevator problems

假設這人有 50kg, 取 $g = 10 \text{ m s}^{-2}$

- 電梯是均速率

the elevator is constant velocity:

$$N = mg = 500\text{N}$$

- 電梯以 1 m s^{-2} 向上加速

acceleration upwards with 1 m s^{-2} :

$$\Rightarrow N - mg = ma$$

$$\Rightarrow N = 550\text{N}$$

感覺重了。feels heavier.

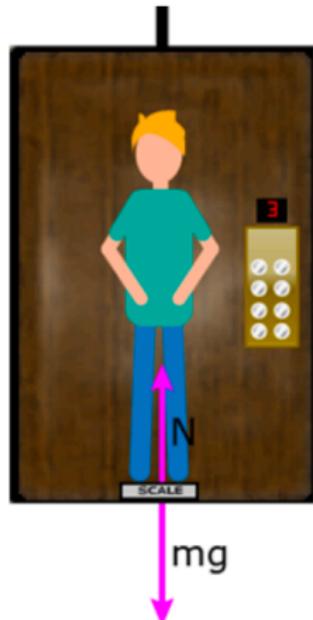
- 電梯以 1 m s^{-2} 向下加速

acceleration downwards with 1 m s^{-2} :

$$\Rightarrow mg - N = ma$$

$$\Rightarrow N = 450\text{N}$$

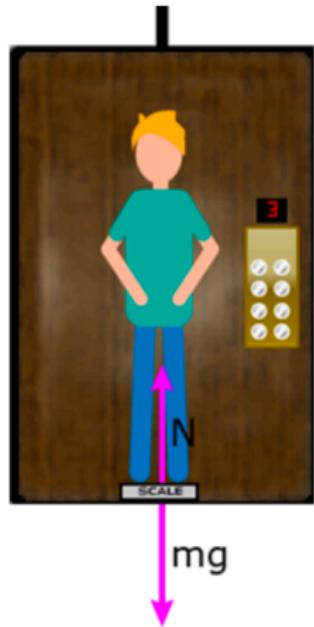
感覺輕了。feels lighter.



升降機問題 Elevator problems

假設這人有 50kg , 取 $g = 10 \text{ m s}^{-2}$

- 電梯以 $> g \text{ m s}^{-2}$ 向下加速
acceleration downwards with $> g \text{ m s}^{-2}$:
 $\Rightarrow N = 0$
- $N = \text{表觀重量 Apparant weight}$



流體阻力 Fluid resistance

流體阻力 Fluid resistance

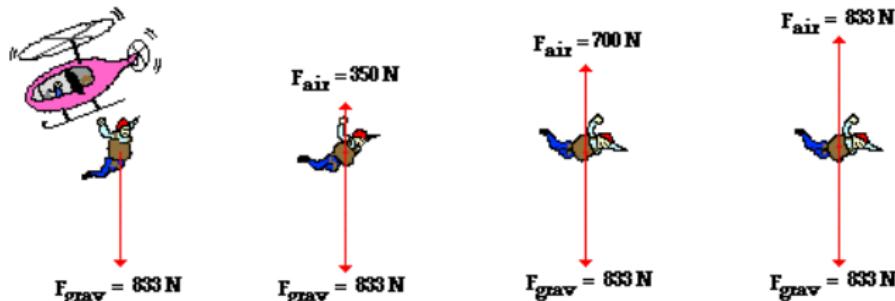
$$f = k \rho v^2 A \quad (2)$$

- k = 常數 constant, ρ = 流體密度 fluid density, v = 速率 speed,
 A = 橫截面面積 cross section area



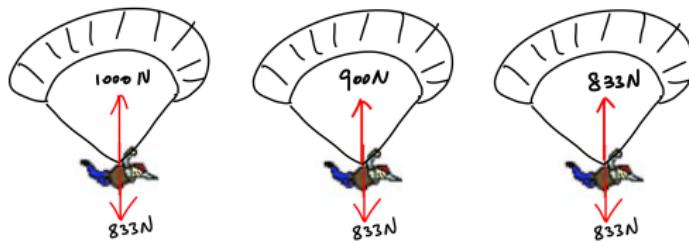
流體阻力 Fluid resistance

- 跳傘員不開跳傘降落時，
When skydiver falls without parachute,
 - 加速度向下 accelerates downwards: $W - f = ma$
 - v 逐漸增加 gradually increases \Rightarrow f 逐漸增加 gradually
 - 直到 f 完全抵消 W，淨力變成零: $W - f = 0$
Eventually f compensate completely W, net force is zero: $W - f = 0$
 - 加速度為零，以**恒定的終端速率**繼續落下。
Acceleration is zero, continues falling with **constant terminal speed**.



流體阻力 Fluid resistance

- 當在終端速率的跳傘員突然打開跳傘，
When skydiver opens his parachute with terminal speed,
 - 橫截面面積突然增加， f 突然增加。
Cross section area increases suddenly, and so f increase suddenly.
 - 淨力向上，跳傘員向下減速。
Net force is upwards, i.e. skydiver decelerates downwards.
 - f 持續下降至淨力為零。
 f continuously decreases until net force becomes zero.
 - 以**更低**的終端速率落下。
Falling with **lower** terminal speed.



流體阻力 Fluid resistance

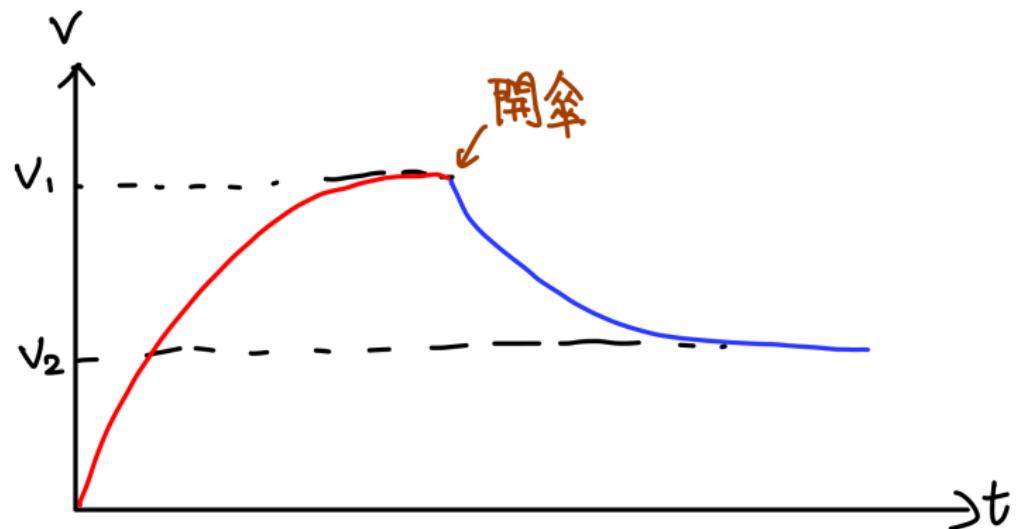
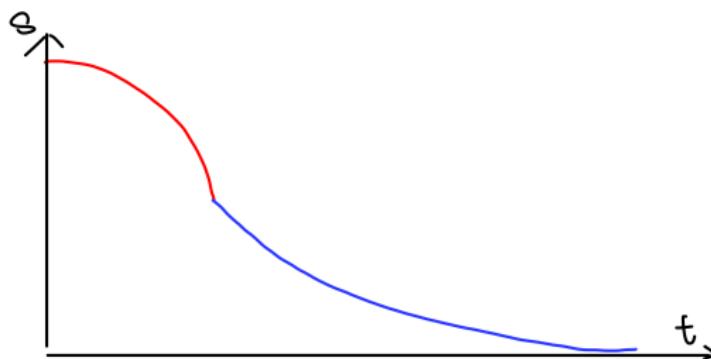
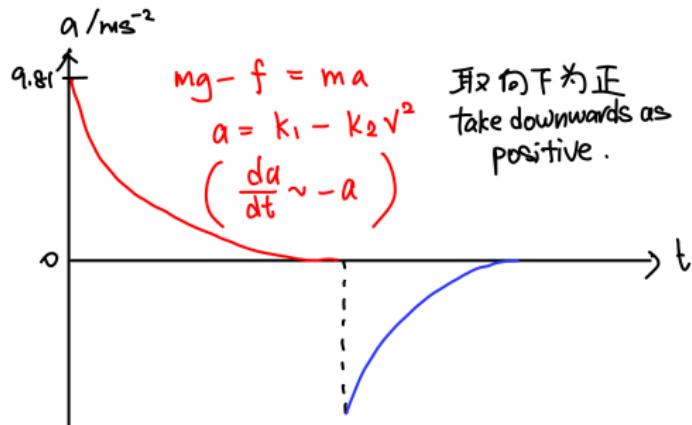


Figure: 跳傘員的 v-t 線圖 v-t graph of a falling skydiver

For interested students...

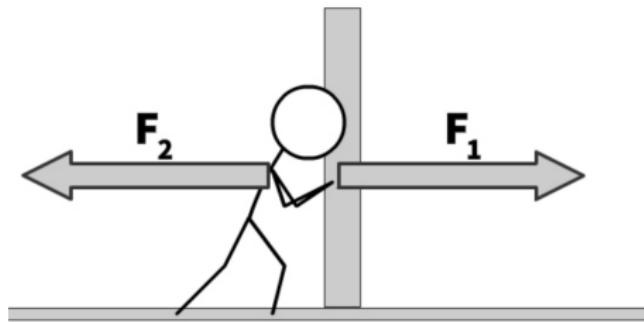


牛頓第三定律 Newton's third law

牛頓第三定律 Newton's third law

力總是成對出現。這些成對的力稱為作用力-反作用力對。

Forces always appear as pairs. These force pairs are known as action-reaction pairs.



牛頓第三定律 Newton's third law

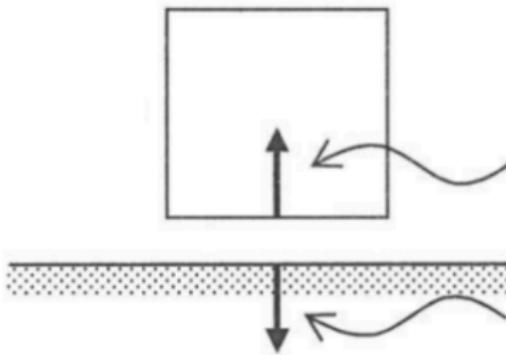
- 作用力和反作用力的特性:

Properties of action and reaction forces:

- ▶ 量值相同 same magnitudes
- ▶ 方向相反 different directions
- ▶ 作用於不同的物體 acting on different bodies
- ▶ 必須屬於同一種力 same type of force

牛頓第三定律 Newton's third law

重量 Weight :

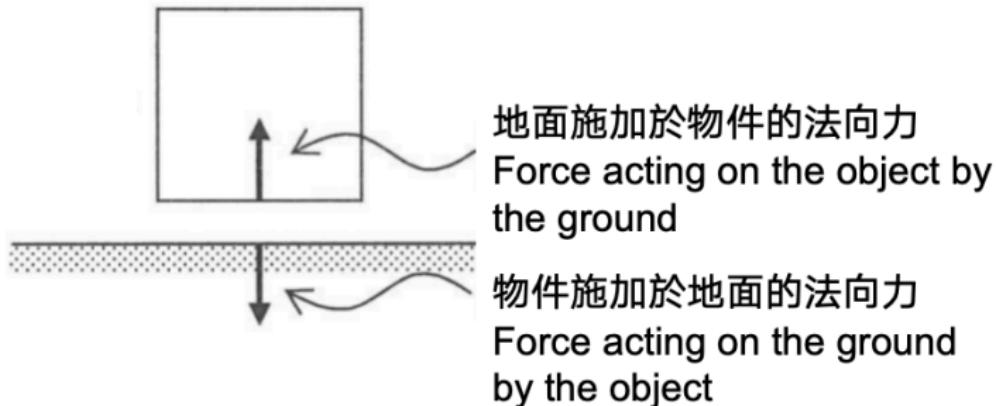


地面施加於物件的法向力
Normal reaction acting on the object by the ground

物件施加於地面的法向力
Normal reaction acting on the ground by the object

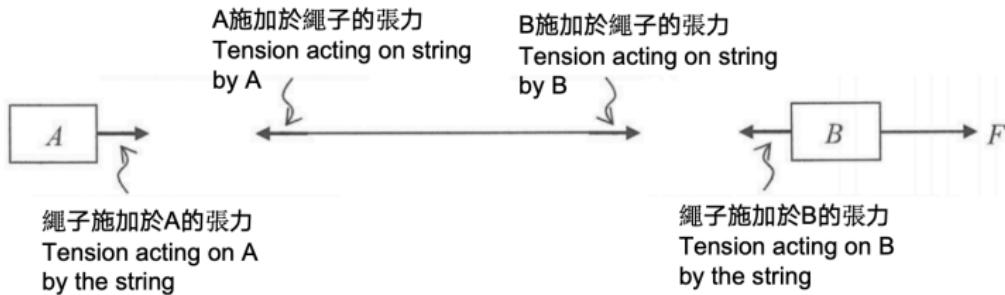
牛頓第三定律 Newton's third law

法向力 Normal reaction :



牛頓第三定律 Newton's third law

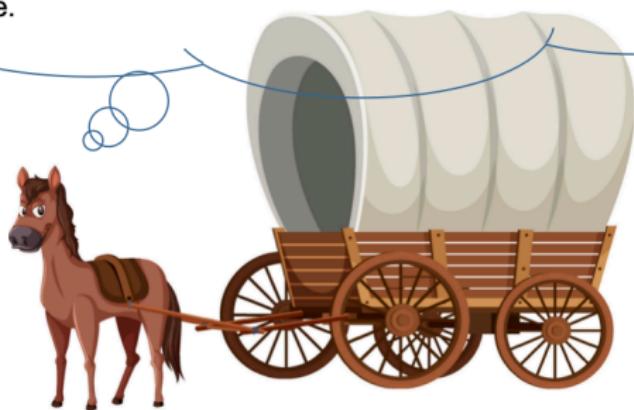
張力 Tension :



牛頓第三定律 Newton's third law

無論我向前施加多少力，馬車總有相同且相反方向的反作用力把我往後拉，而這兩個力因為互相抵消，所以我永遠動不了

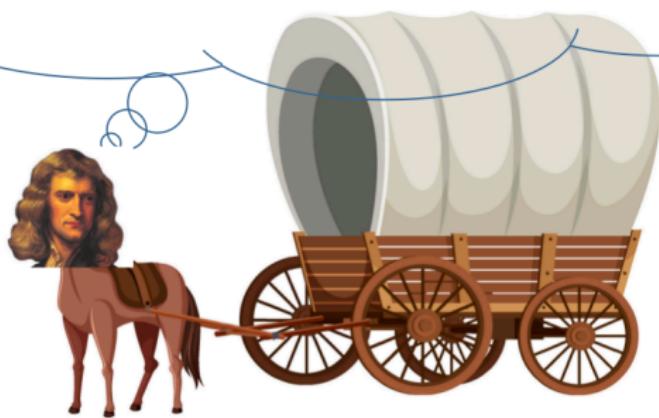
No matter how much force I apply forward, the carriage always exerts an equal and opposite reaction force that pulls me backwards. These two forces cancel each other out, so I can never move.

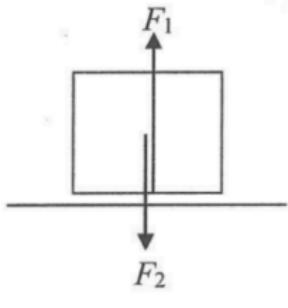


牛頓第三定律 Newton's third law

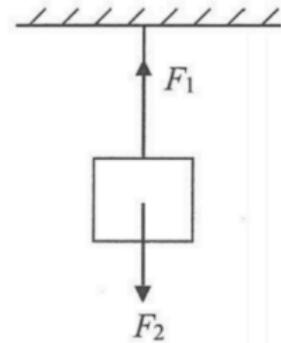
因為作用力和反作用力作用於不同物體，它們是不可能互相抵消的

Because action and reaction forces act on different objects, they cannot possibly cancel each other out.





F_1 = 法向力 Normal reaction
 F_2 = 重量 Weight

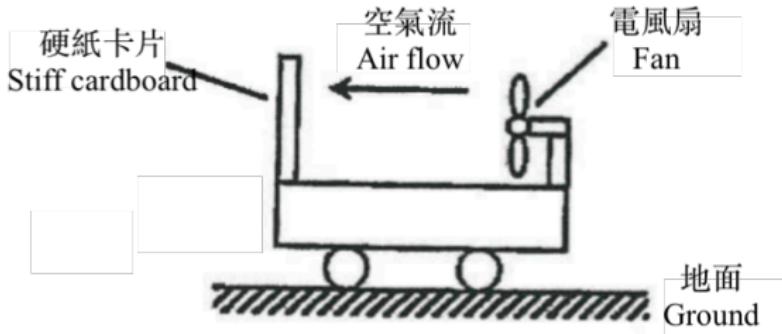


F_1 = 張力 Tension
 F_2 = 重量 Weight

- F_1 和 F_2 不是作用力反作用力對的理由：
 Reasons why F_1 and F_2 are not action reaction pair:

- ▶ 作用於相同物體 Act on same object
- ▶ 屬於不同種力 Different types of forces

例題 Example



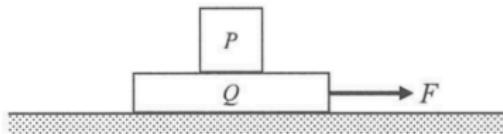
在小車的一端裝了電風扇，一張硬紙卡片固定在另一端且面向電風扇。當電風扇啓動後，小車將會怎樣運動？

- (a) 不動 (b) 向左走 (c) 向右走 (d) 在原地往返運動

An electric fan is installed on one end of the small car, and a stiff cardboard is fixed on the other end of the fan. When the electric fan is activated, how will the car move?

- (a) Remain at rest (b) Move left (c) Move right (d) Move left and right periodically

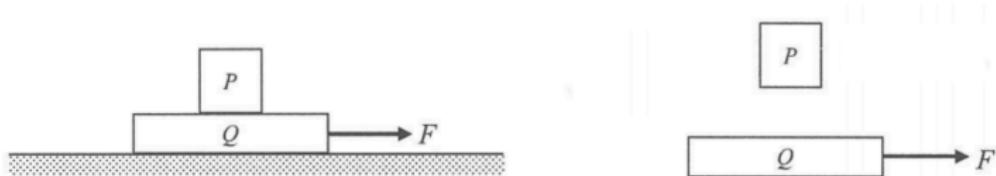
例題 Example



P 是 2kg，Q 是 3kg，F 是 6N，所有接觸面都是光滑的。求 P、Q 的加速度。

P is 2kg, Q is 3kg, F is 6N, and all contact surfaces are smooth.
Calculate the acceleration of P and Q.

例題 Example



P 是 2kg，Q 是 3kg，F 是 6N，現在地面仍是光滑的，但 P 和 Q 之間存在摩擦力，使得 P 和 Q 能同時移動。求摩擦力的量值。

P is 2kg, Q is 3kg, and F is 6N. The ground is still smooth, but there is friction between P and Q which allows them to move together.

Calculate the magnitude of the frictional force.

作用力和反作用力的日常應用 Daily application of action and reaction pair



- 與地面產生的摩擦力大者勝出。
Whichever side has greater friction on the ground wins.

作用力和反作用力的日常應用 Daily application of action and reaction pair



- 船槳向後推動河水，河水對船槳施加反作用力使船前進。
The oar exert backward force on the river water, and the river water exerts a reaction force on the oar, causing the boat to move forward.

作用力和反作用力的日常應用 Daily application of action and reaction pair



- 助跑器為運動員在比賽開始時提供穩定且有爆發力的推動。
Starting block is used to provide a stable and explosive push-off for athletes at the start of a race.