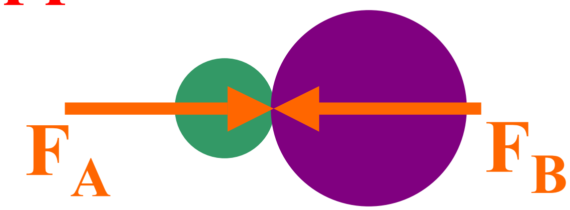
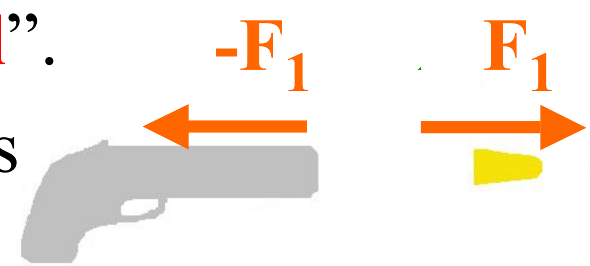
Recap: Newton's 3rd law (Action and Reaction)

- Forces are caused by **interactions** between two (or more) objects. Each exerts an **equal** but **opposite** directed force on the other.
- **Forces** always occur in **pairs**.
- The two **forces always** act on **different objects**.



$$F_A = - F_B$$

- Ex: **Pushing a chair** – your applied force acts to determine chair's motion. The reaction force produced by chair acts on **you**.
- Reaction force sometimes called "**recoil**".
- Ex: Firing a gun – Large force produces high acceleration of low mass bullet.



- To reduce acceleration of recoil, increase effective mass – hold gun rigid with body (improved aim).

Internal and External Forces:

- **External** forces act on the object to cause motion.
- An **internal** force has **no effect** on the object's overall motion.

Examples: **Internal force**

1. You cannot lift yourself up and fly!!

All the forces you can exert on yourself are counteracted and **net force = 0**, as no interaction with **external** objects.

Internal and External Forces:

Examples: Internal force

2. You **cannot push** a car from the inside!!

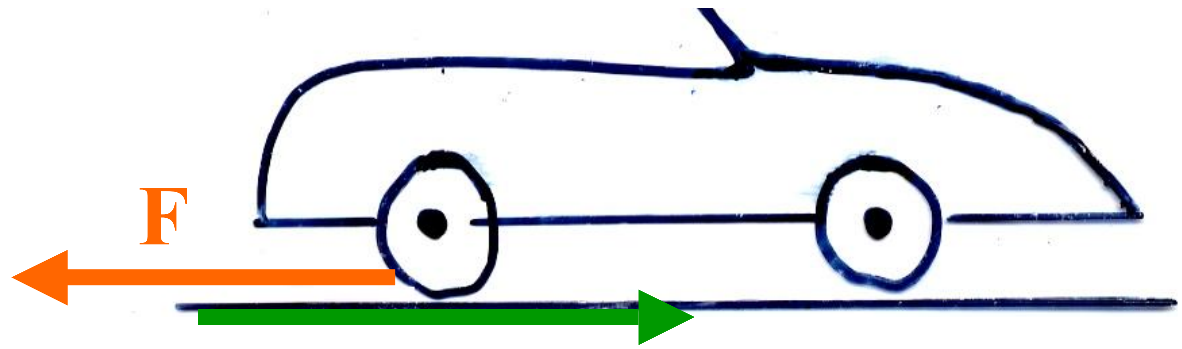
If you push forward on steering wheel, it pushes you back against your seat, **net force = 0**!

So how does a car work?

- The engine also cannot push the car by itself as it is part of the car...(internal force)

So how does a car work?

- It needs rotating tires in contact with another body (ground) to push against.
- Makes use of friction force:



Reaction force produces forward acceleration.

-F

External force pair

Application's of Newton's Laws:

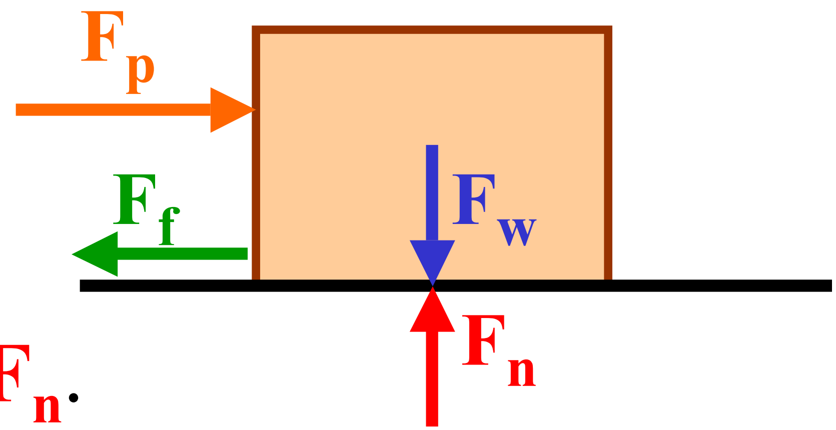
- Forces arise due to **interactions** between different objects.
- **Pushing a heavy box:**

  4 external forces act on the **box**

  (from 4 separate interactions)

Application's of Newton's Laws:

- Pushing a heavy box (4 **external** forces act on the **box):**
- Weight (F_w) due to interaction with Earth.
- Upward normal force (F_n) exerted by floor on the box.
- As no vertical motion $F_w = -F_n$.
- Pushing force (F_p).
- Frictional force (F_f) exerted by floor – resistance to motion. (Not a reaction force.)



What happens as force F_p increases?

- In order for the box to move, F_p must **exceed** frictional force F_f. (ie. If $F_p = -F_f$, then no motion).
- When $F_p - F_f$ is **greater than zero**, there is a **net force** which produces an **acceleration** of the box:

$$(F_p - F_f) = m\,a$$

What happens as force F_p increases?

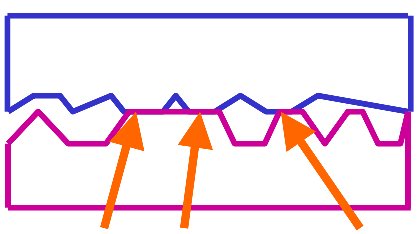
- Once the box is moving at a suitable velocity, you can **reduce the applied force** F_p so that it **just balances** the frictional force:

  $F_p = -F_f$ **no** further acceleration occurs.

- The box will **continue to move** at a **constant velocity.** Why? **Newton's 1st law!**
- **So:** Initially a **higher force** is needed - we often say "to overcome friction"….but it's really to **overcome box's inertia** as well as **friction** is **ever-present**!

What is friction?

- **A resistive force opposing motion.**
- So far we have assumed many examples with **no friction** but friction is a very important force in our lives…
- **No surface** is perfectly smooth when viewed at the atomic level!
- **Frictional forces** arise between two surfaces in **contact** because they tend to **dig into each other**.



contact points

Two objects in contact supported by a few high spots or "prominences".

- **Friction** is known to be **independent of surface area** – **counter intuitive!**
- **Reasoning:** If reduce area, the number of contact points reduces. This causes the pressure to increase at these points, which in turn flattens them more and results in an **increase in contact area.**
- **Overall effect: total "contact area" about the same!**

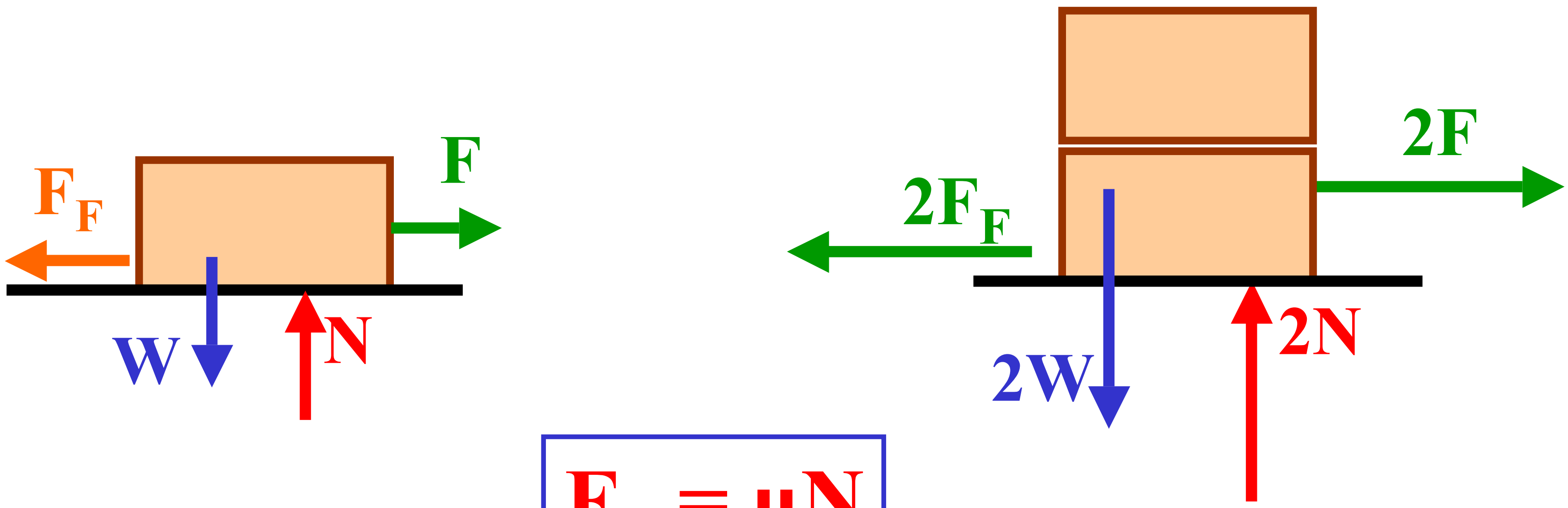
- There are **no simple** “laws of friction”, as it is affected by several factors, eg:
  - **Surface quality (roughness)**
  - **Type of material**
  - **Presence of lubricants…**
- Lubricants act to **separate the two surfaces** and allow them to “float” – greatly reducing the friction.

Rules of Thumb: (Leonardo da Vinci, 15th century, knew about these)

- **Static** and **Kinetic** friction:
- A resistive force acting **parallel** to **surface, opposing** motion.
- **Independent of surface area!**
- Highly **dependent on types** of materials in contact (ie. their coefficient of friction).

Rules of Thumb: (Leonardo da Vinci, 15th century, knew about these)

- Proportional to **magnitude** of the **normal force** (N).



$$F_F = \mu N$$

Static Friction ($F_s = \mu N$)

- Opposes impending motion and arises from need to **rip apart** bonded contact points.
- In order for **motion to occur** the applied force must **exceed** the **maximum** static frictional force (F_S)

$F > F_S$ (as in box example)

Static Friction ($F_s = \mu N$)

Examples – static friction:

- **Cold welding** – very clean flat surfaces can literally **fuse together** at contact points, creating a cold weld – very difficult to pull apart.
- **Walking** (Newton's 3rd law)
  Friction allows us to **push backwards** with our feet and the **reaction** moves us **forward**. **Foot is stationary** with respect to ground; force cannot exceed F_S or will slip!
- **Driving** – as **no** horizontal motion of tread with respect to ground, (no skidding) **car tires also utilize static friction!**

Kinetic Friction

- Retarding force exerted on a **sliding body** in contact with another surface once it's in motion.

$$F_k = \mu_k N$$

- The kinetic friction force F_k is **equal** to and opposite to the **applied force** if moving at **constant velocity**.

- **Examples:** - Skidding tires, brakes locked!

  - Burning rubber, drag cars...

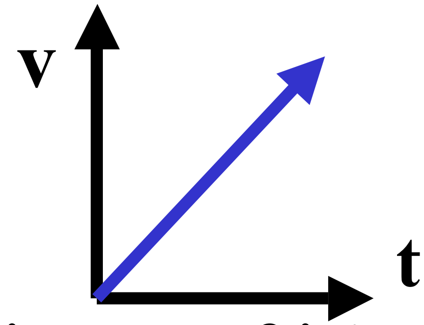
Examples of friction coefficients

Material	μ_{static}	$\mu_{kinetic}$
Rubber on concrete (dry)	2.0	1.0
Rubber on concrete (wet)	1.5	0.97
Steel on steel	0.6	0.2
Glass on glass	0.95	0.4
Wood on leather	0.5	0.4
Steel on ice	0.1	0.06
Waxed ski on snow	0.1	0.05
Teflon on steel / teflon	0.04	0.04

Result – Kinetic friction usually less than static friction → antilock brakes!

Sky Diving – Terminal Velocity

- An object falls at constant acceleration 'g'.
- If no air resistance its velocity will increase uniformly with time:



- Downward force F = m g
- **Air resistance (R)** – we all have experience of it!
- Like friction, air resistance is a **force** that opposes motion, and

R → **Increases with speed**
R → **Increases with surface area**

Net downward force:

$$F_{net} = m\,g - R = m\,a$$

As speed increases, R increases & acceleration decreases.

Key: When $R = m\,g, \; F_{net} = 0$ **no more acceleration!**

- The condition when **R = m g** is called "**terminal velocity**".

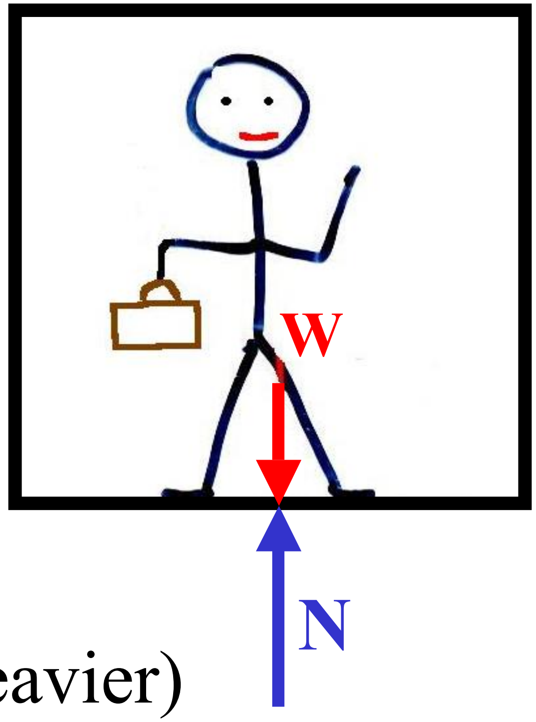
Terminal velocity depends on object's WEIGHT!

- Thus, more **massive** (heavier) **objects** will have a **higher terminal velocity**!
- A **feather** is light and has a large surface area, therefore its **terminal velocity** will be **very low**.
- A sky diver's **terminal velocity** is much larger, about **100 mph (160 km/hr)** depending on weight and surface area.
- This is the origin of Aristotle's mistake, when he mistook the reason why heavier objects fall faster than lighter ones!
- Note: Terminal velocity not limited to gases.
- **In a liquid the resistance force R is usually much larger and terminal velocity occurs at lower velocities.**

Apparent Weight

Riding in a elevator– **why does our weight appear to change** when we start up (increase) and slow down (decrease)?

Our sensation of weight change is due to a **force exerted** on our feet by the **elevator** floor (normal force N). If force greater we feel heavier and vice versa.



Eg. Upward accelerating elevator:

As accelerating, there must be a net upward force.

(2nd law) $\mathbf{F_{net} = N - W = m\,a}$

But our true weight: $\mathbf{W = m\,g}$

Apparent weight: $\mathbf{N = W + ma}$

$$\mathbf{N = m\,(g + a)}$$ (i.e. heavier)

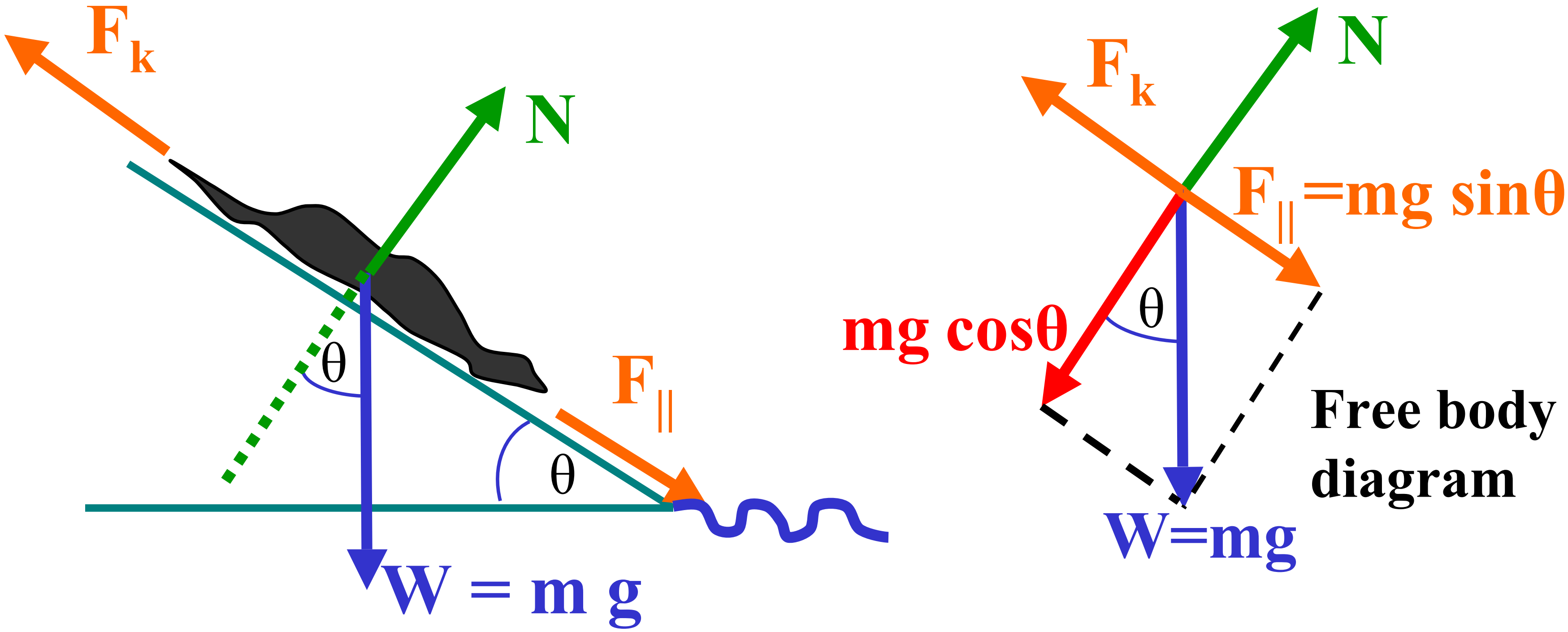
If lift accelerating downwards (or decreasing upwards):

$$\mathbf{N = m\,(g - a)}$$ (ie. lighter)

Free-Falling

- When you jump off a wall, or throw a ball or drop a rock in a pool, the object is free-falling ie. falling under the influence of gravity.
- Question: What happens to our apparent weight in free-fall?
- Nasty Exp: Cut elevator wires so its downward acceleration a = g (i.e. free-fall)!
- Apparent weight $N = m (g - a)$
- But $a = g$, so $N = 0$ i.e. no normal force.
- **"Weightless" is zero apparent weight.**
- **Everything is falling at same rate, so no normal force is needed to support your weight.**
- Ex: Aircraft flying in a parabolic path can create weightless conditions for up to 30 s!
- Spacecraft / astronauts in orbit are weightless as they (and the spacecraft) are **continuously free-falling** towards the Earth!!

Example: Sea Lion splash!



Resolve the weight force into two components – parallel and perpendicular to ramp.

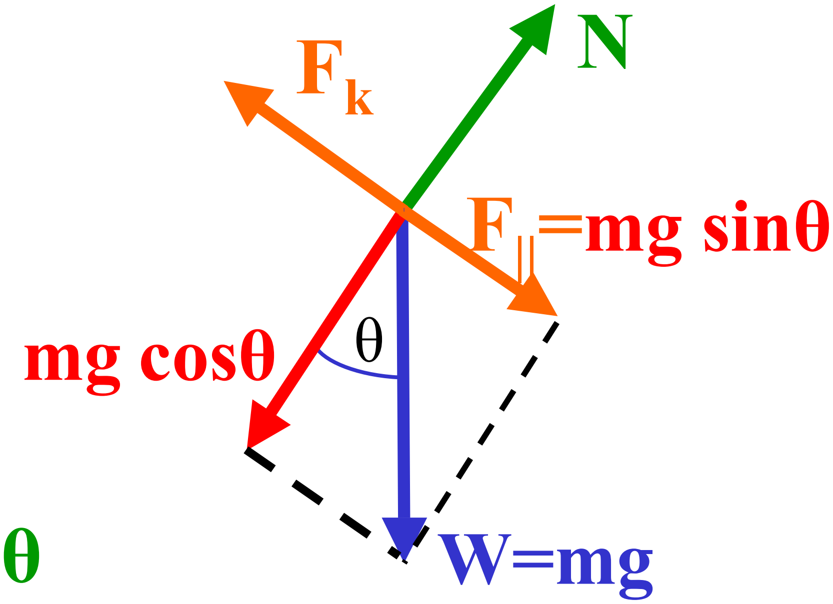
Result: **- Down slope force $F_{||} = m\, g \sin\theta$**

- Normal force $N = m\, g \cos\theta$

Net force down slope:

$$F_{net} = F_{||} - F_k$$

$$= m\,a$$



but friction, $F_k = \mu_k N$

$$= \mu_k\, mg \cos\theta$$

Thus: $F_{net} = m\,g \sin\theta - \mu_k\, m\,g \cos\theta = m\,a$

$$a = g\,(\sin\theta - \mu_k \cos\theta)$$

For $\theta = 23^o$, $\mu_k = 0.26$, $g = 9.81\ m/s^2$, **then**

$$a = 9.81\,(\sin 23^o - 0.26 \times \cos 23^o)$$

$a = 1.5\ m/s^2$ **(note: 'a' is independent of mass)**