



# MECA0063 : Braking systems

---

Pierre Duysinx

Research Center in Sustainable Automotive  
Technologies of University of Liege  
Academic Year 2021-2022



## Bibliography

---

- T. Gillespie. « Fundamentals of vehicle Dynamics », 1992, Society of Automotive Engineers (SAE)
- J.Y. Wong. « Theory of Ground Vehicles ». John Wiley & sons. 1993 (2<sup>nd</sup> edition) 2001 (3<sup>rd</sup> edition).
- R. Bosch. « Automotive Handbook ». 5<sup>th</sup> edition. 2002. Society of Automotive Engineers (SAE)
- R. Bosch. « Automotive Brake Systems ». R. Bosch Publishers. 1995.
- R. Bosch. « Safety, Comfort, and Convenience Systems. Function regulation and components. » Bentley Publishers 2006.
- « An Introduction to Modern Vehicle Design ». J. Happian-Smith ed. Butterworth-Heinemann. 2002
- "Automotive Engineering: Powertrain, Chassis System, and vehicle Body". D. Crolla ed. Butterworth-Heinemann. 2009



## Bibliography

---

- H. Heisler. Vehicle and engine technology. 2<sup>nd</sup> edition. Butterworth Heinemann. 2003.
- R. Mèmeteau. Technologie fonctionnelle de l'automobile : Tome 2, La transmission, le freinage, la tenue de route et l'équipement électrique. Tome 2. Dunod, Paris.
- R. Juvinall & K. M. Marshek. Fundamentals of Machine Component Design. Fifth edition. John Wiley and Sons. 2012



# Braking system architecture

---

- Introduction
- Braking performance
  - Weight transfer
  - Optimal braking distribution
  - Non ideal braking
- Brakes devices
  - Drum brakes
  - Disk brakes
- Braking systems
  - Master cylinder
  - Master Vac
  - Proportioning valve



# INTRODUCTION

---



# Introduction

---

- Brakes are primarily used to decelerate a vehicle beyond its road resistance and the braking drag of the engine
- Brakes generally transform the kinetic energy of the vehicle into heat
- Brakes can also be used to:
  - Keep a constant speed
  - Keep the vehicle at standstill

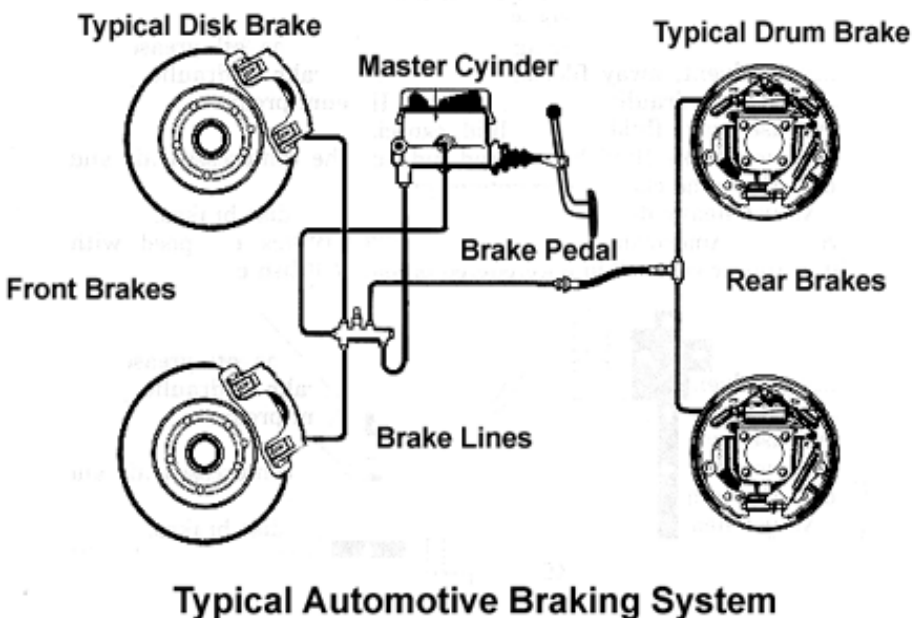


# Introduction

---

- One distinguishes the different categories of braking systems
  - **Service brake system**: generally decreases the speed while driving
  - **Emergency brake system**: has to take over the function of the service brake system when failing
  - **Parking brake system**: prevents unwanted motion of the vehicle when parked
  - **Continuous service braking systems**: for longer uninterrupted braking and frequent stops for instance in urban heavy vehicles
- The service, emergency and parking brake systems directly work on the wheels
- The brake elements of the continuous service generally act on the driveline

# Introduction



- A common brake system includes
  - **Control device**: pedals / hand-brake lever
  - An **energy source** which generates, stores and releases the energy required by the braking system
  - **Transmission device**: components between the control device and the brake
  - **The wheel brake or foundation brakes** generating the forces opposed to the vehicle motion

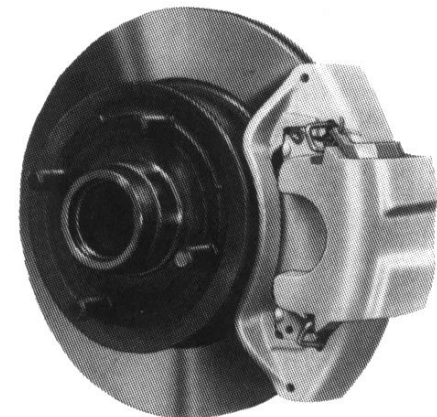
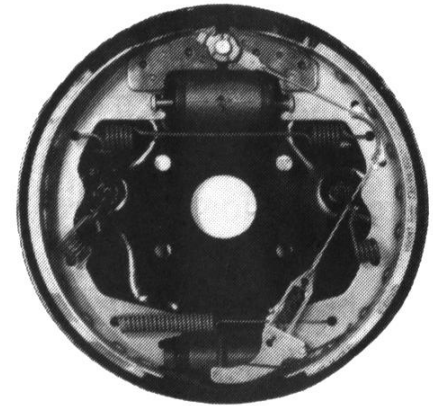


# BRAKE DEVICES

---

# Types of brakes

- Drum brakes
  - They used to be the usual brakes because of their high mechanical advantage and because of their ability to include parking brakes
- Disk brakes
  - Their mechanical advantage is lower and they require higher actuation forces
  - They require also additional developments to introduce parking brakes
  - They yield more constant braking forces



# Drum brakes



The drum spins  
with the wheel



The flange is fixed with  
respect to the chassis



# Drum brakes

---



©2000 How Stuff Works

Brake shoe



©2000 How Stuff Works

Drum (inside view)

# Drum brake

- Braking factor is the mechanical advantage between the actuating force (input) and the braking force (output)

$$\sum M_A = e P_a + n \mu N_A - m N_A = 0$$

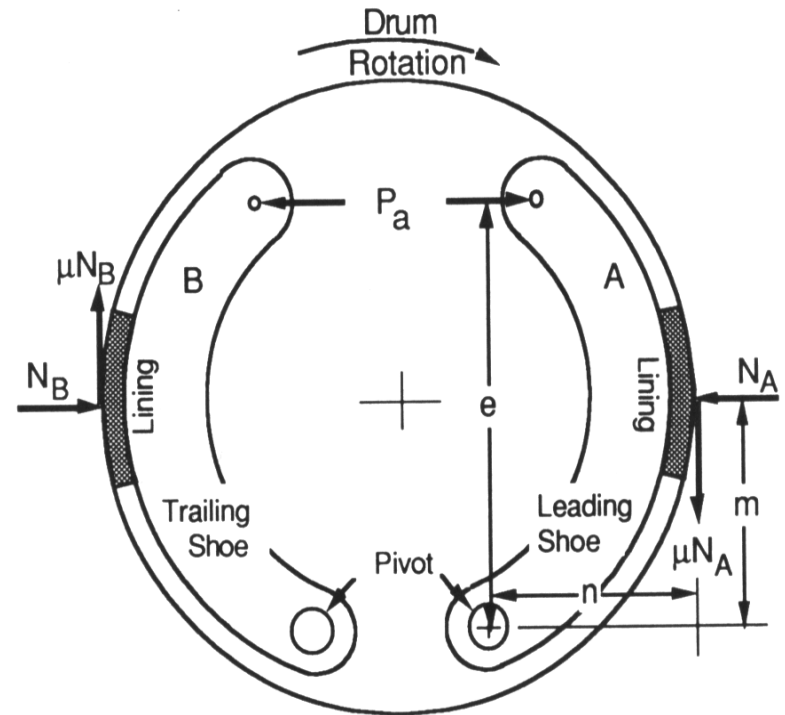
$$F_A = \mu N_A$$

$$F_B = \mu N_B$$

- It comes

$$\frac{F_A}{P_a} = \frac{\mu e}{m - \mu n}$$

$$\frac{F_B}{P_a} = \frac{\mu e}{m + \mu n}$$





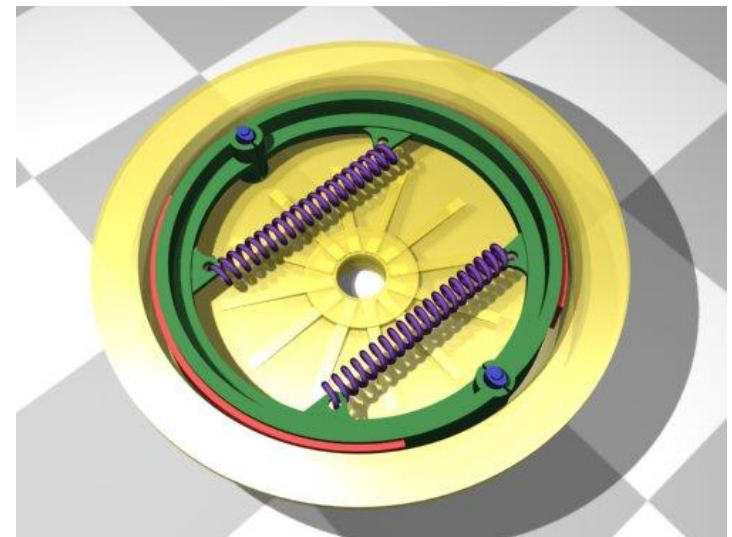
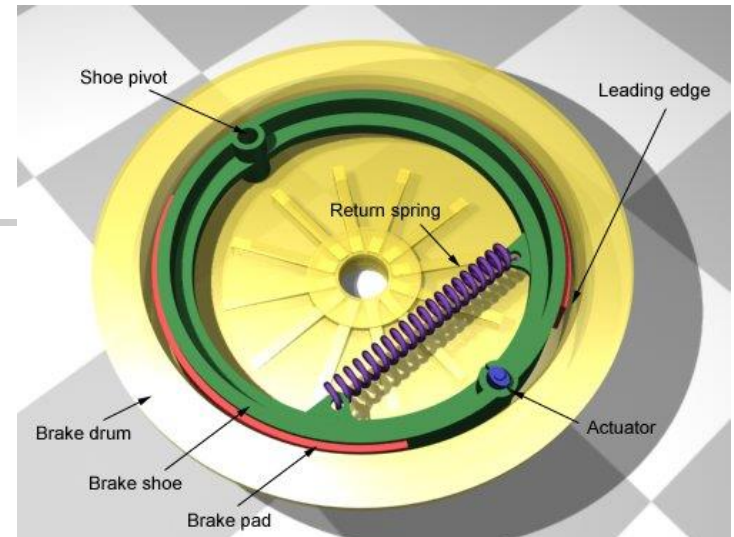
# Drum brake

---

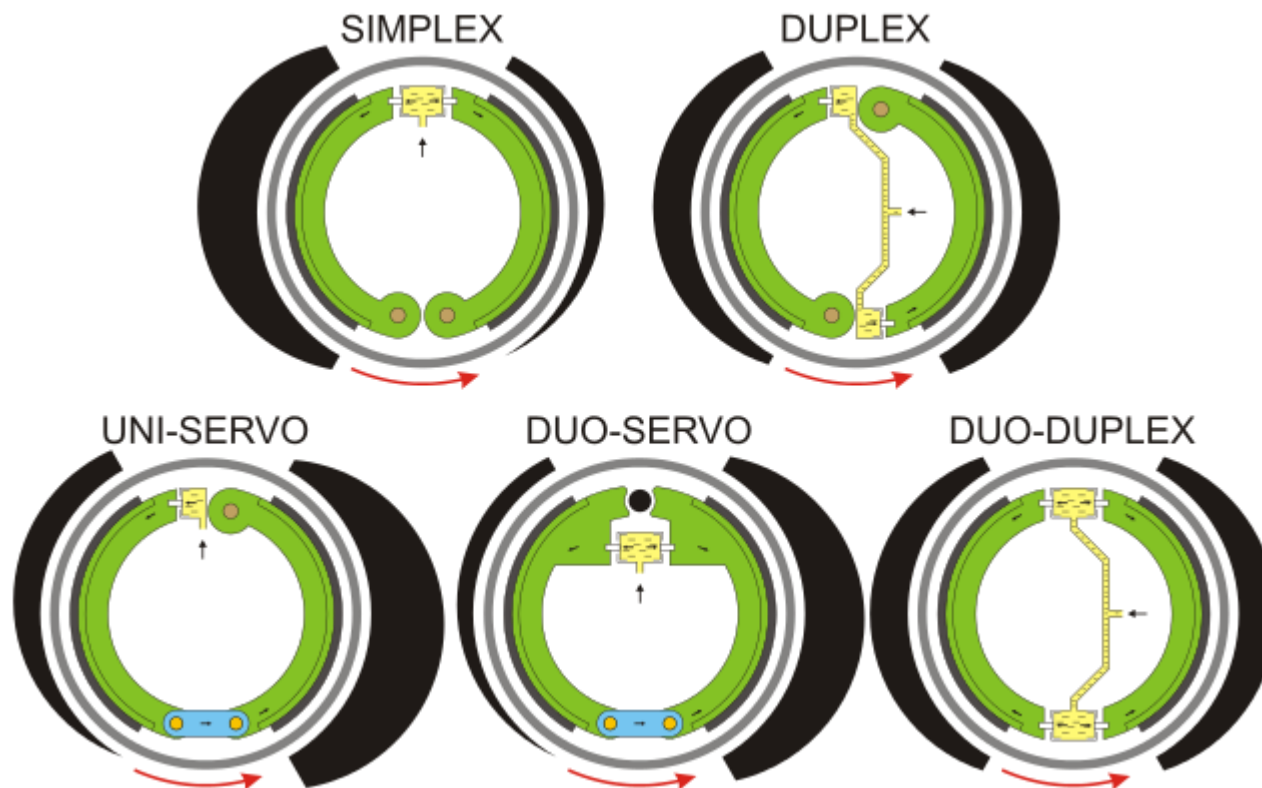
- The **leading shoe A**.
  - The friction force creates a moment that applies the shoe against the drum and the lining pad and thus increases the friction force
  - The system is self actuated so it yields a high mechanical advantage
  - This may lead to a brake locking
- The **trailing shoe B**
  - The friction force tends to create of repulsive moment thus reducing the contact force
  - The mechanical advantage is lower
  - It requires a higher actuation force
  - It is not subject to self locking
- Smart combination of trailing and leading shoes and their lining materials may lead to on-demand braking factors

# Drum brakes

- The conventional design consists in an internal brake shoe that is applied on the inner surface of the drum.
- The usual drum brake includes two shoes in one drum.
- According to the type of the clamping force and of the shoe support, the drum brakes are classified in different categories:
  - Simplex-brake
  - Duplex-brake
  - (uni)-Servo brake
  - Duo-duplex-brake
  - Duo-servo-brake



# Drum brakes



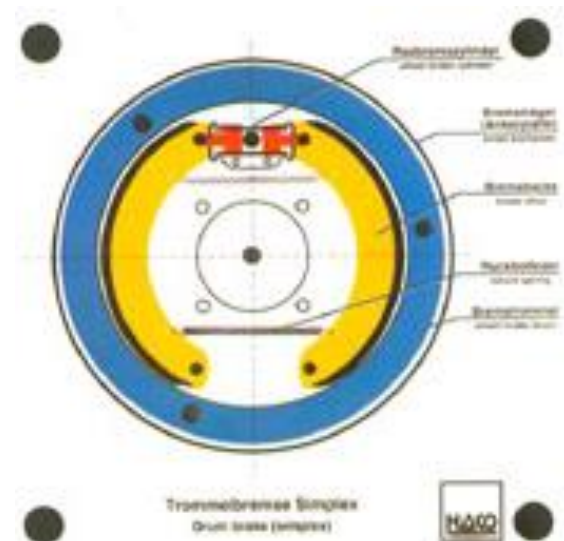
# Drum brake

- **Hydraulic Simplex Brakes**
- They are equipped with **double brake cylinder** and **an axle fixed rotation point**.
- They combine a leading and trailing (secondary) shoe in a single drum is called a **simplex**, or leading/trailing type.
- They are characterized by a fixed supporter between the bottom ends of the brake shoes.
- This enables a parking brake function without clearance.



# Drum brake

- **Hydraulic Simplex Brakes**
- This type of brake is equally effective for forward and reverse braking and offers stable braking force.
- Another advantage of this kind of brake is its constant brake characteristic.
- In general, it is used most often as a rear brake in passenger vehicles.



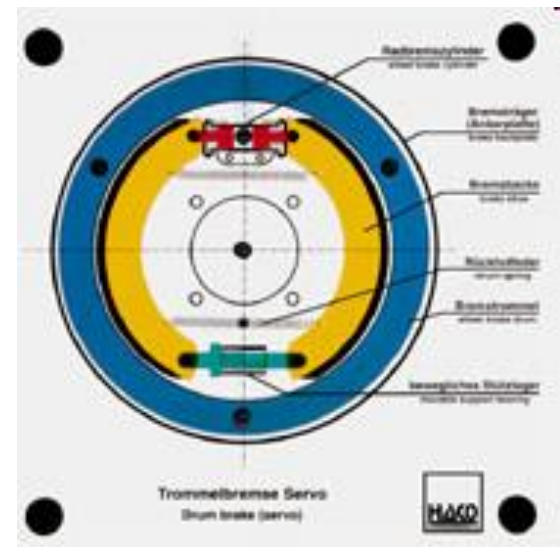
# Drum brake

- **Hydraulic Duplex Brakes**
- This type of drum brake (**Duplex**) has two leading brake shoes. (or when backing-up, with two trailing brake shoes!)
- Structurally, it has two separate wheel cylinders.
- During forward movement of the vehicle, both shoes act as leading ones, providing superior braking force.
- This type is used where such strong force is required, mainly in trucks and other commercial vehicles.



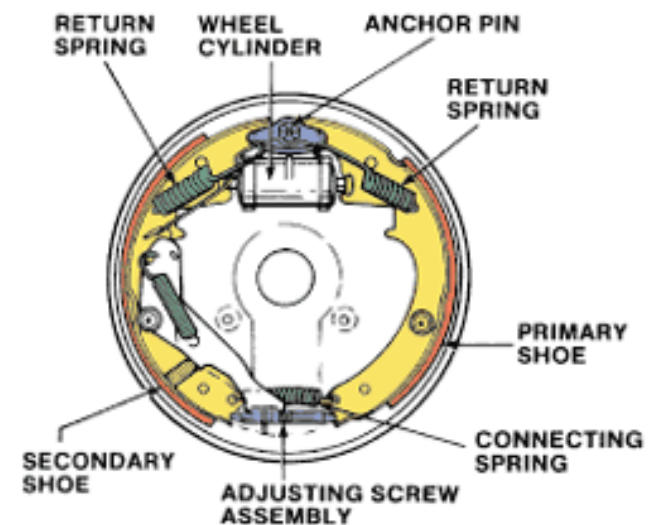
# Drum brakes

- **Hydraulic Servo Brakes**
- They are actuated by a single double brake cylinder and **include a sliding support between the bottom ends of the brake shoes.**
- The sliding support transfers the tangential forces of the primary brake shoe onto the secondary shoe. The transferred force through the sliding support wedges the secondary side leading shoe into the drum to achieve braking action.
- Servo device results in **significantly higher brake forces at low actuation forces.**

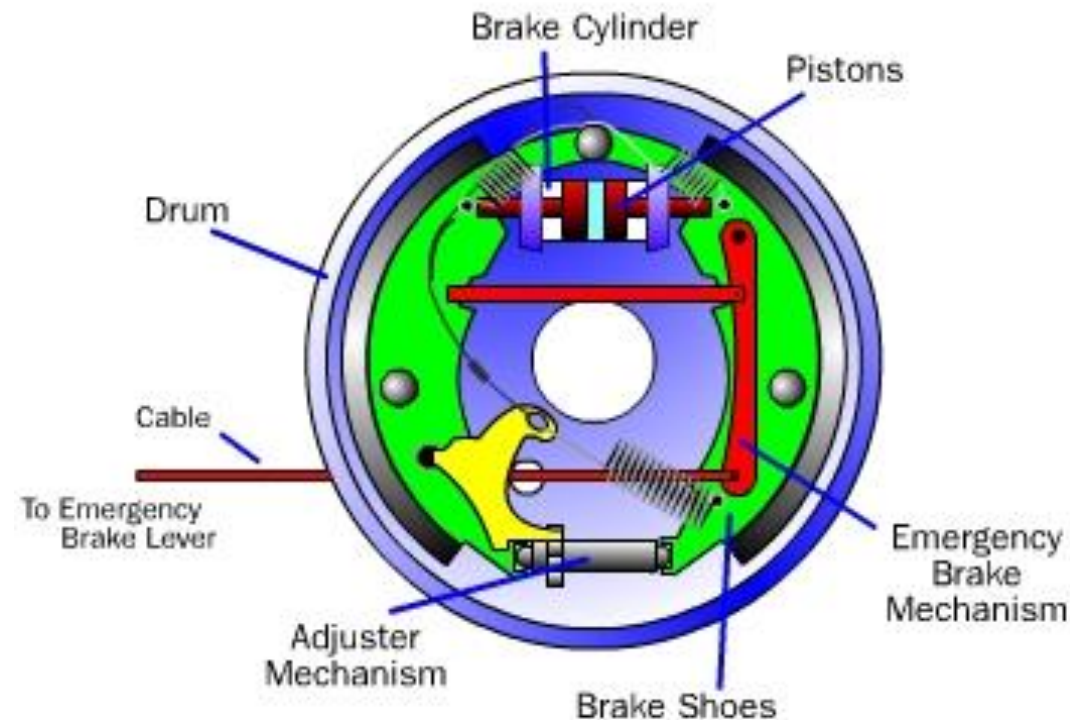


# Drum brakes

- **Duo-servo drum brakes** are an improved version of twin leading construction, where the two brake shoes are linked.
- This type of drum brake provides strong braking for both forward and reverse movement. It is used in commercial vehicles that require especially large braking forces.

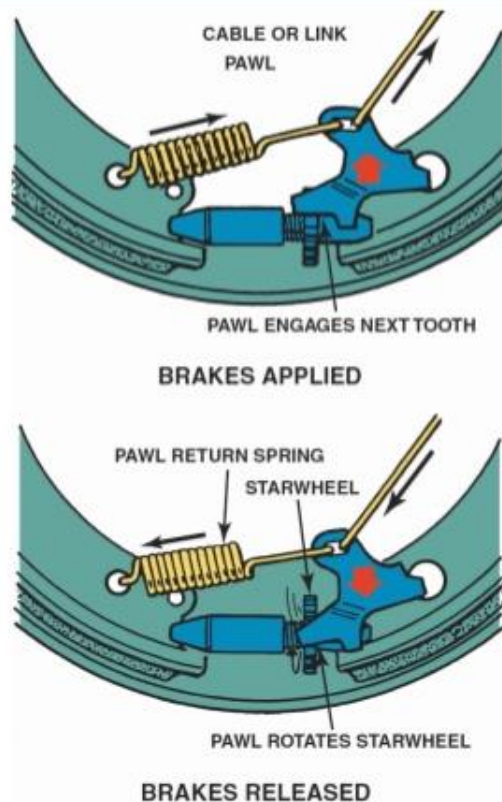


# Drum brakes



- Drum brake with parking brake
  - Operation of the brake shoes via the wheel brake cylinder
  - Function of the leading and trailing shoes
  - Operation of the service brake via the pistons in the wheel cylinder
- Operation of the parking brake via a linkage (in red)
- Adjuster mechanism to reduce the gap due to wear

# Drum brakes



- Automatic brake adjusters: servo brake star-wheel automatic adjusters
- The operation of typical self-adjuster is sketched. Notice that the adjuster automatically moves the adjuster when a gap is present.



## Disk brakes

---

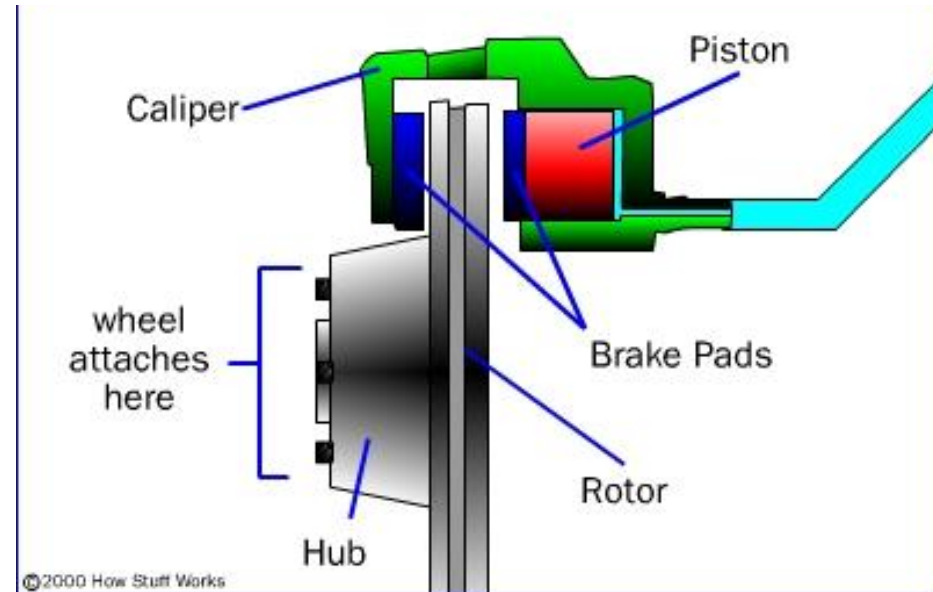
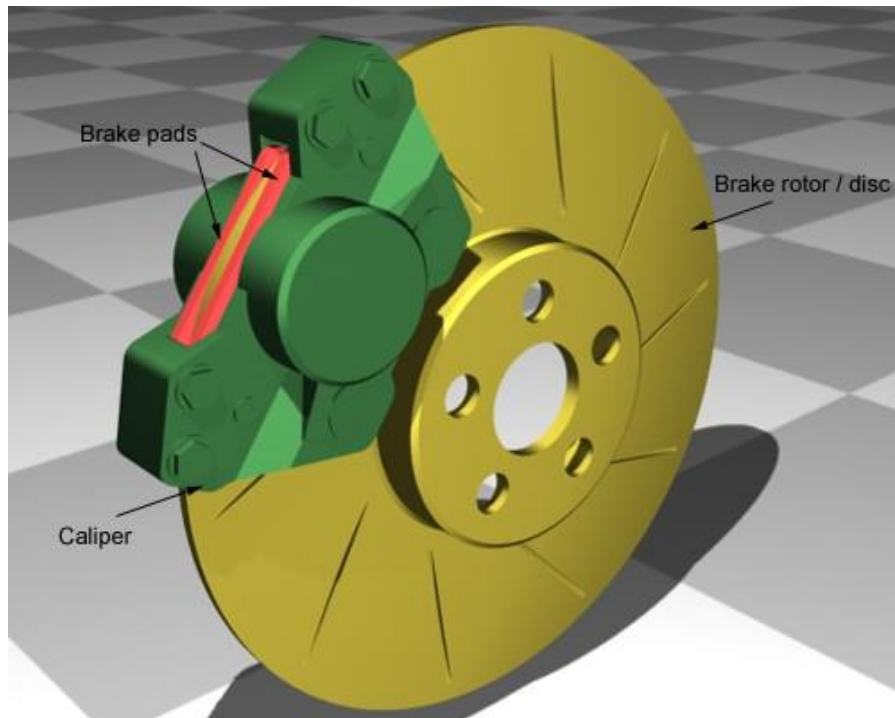


Car



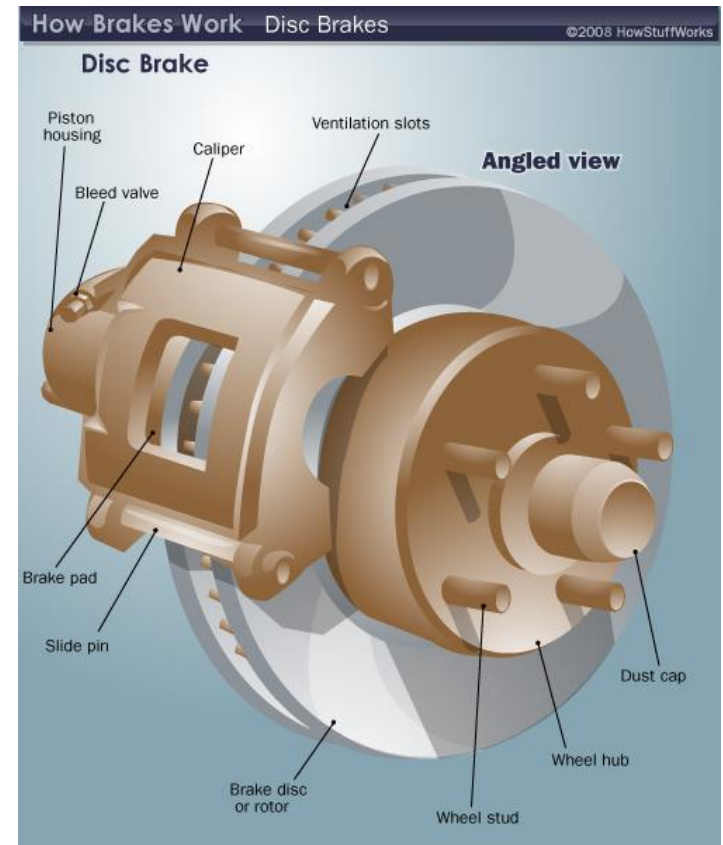
Motorbike

# Disk brakes: definitions



# Disk brakes

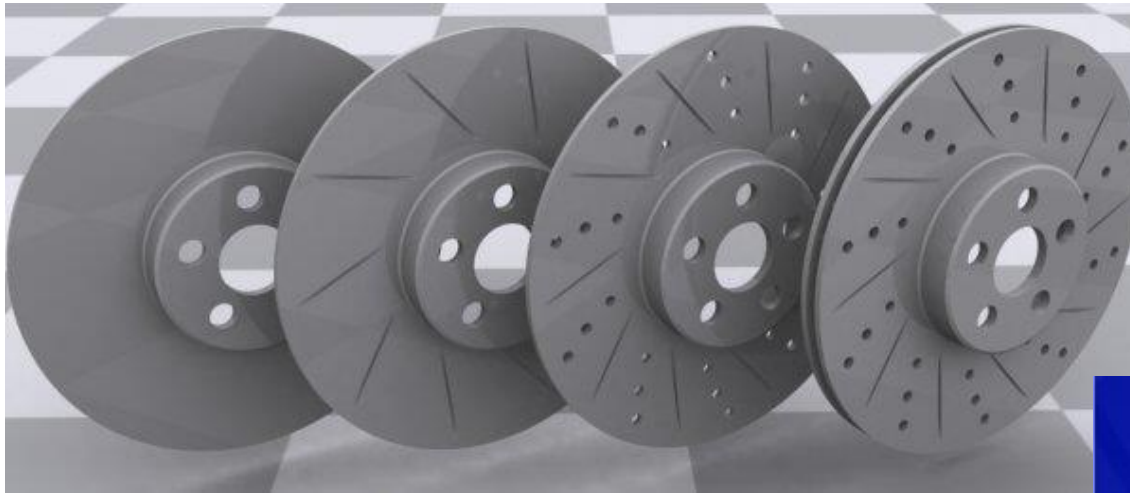
- The disk brake includes
  - A **disk** that is connected to the wheel and so it spins with it
  - A **calliper** that supports one or several pistons on which are mounted the friction pads. The calliper is fixed with respect to the chassis
  - There can be one or several **pistons**
  - **Friction pads** made of high friction materials
- One can distinguish between
  - The fixed calliper
  - The floating calliper or self-adjusting brakes





# Disk brakes

---

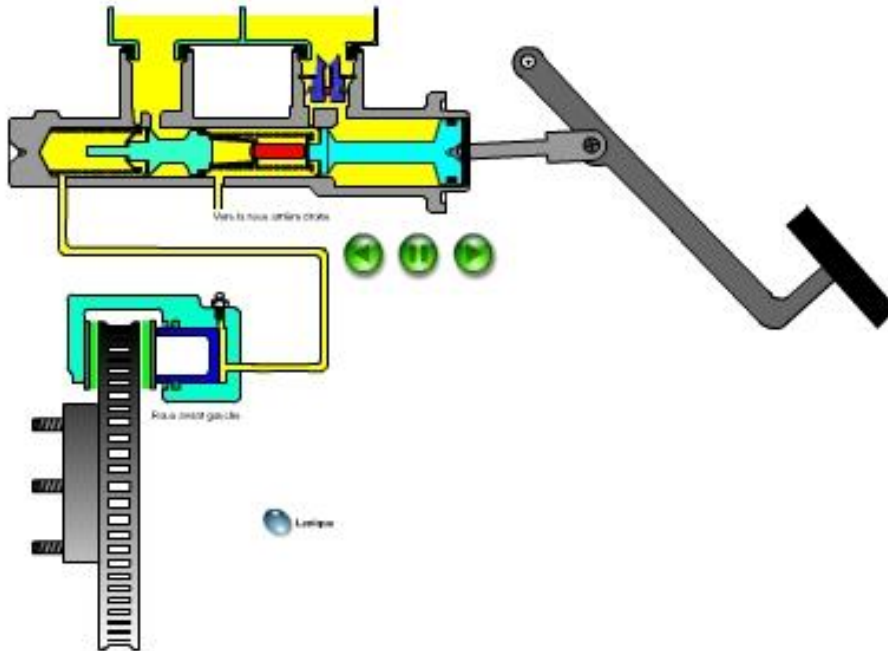


Disk brakes

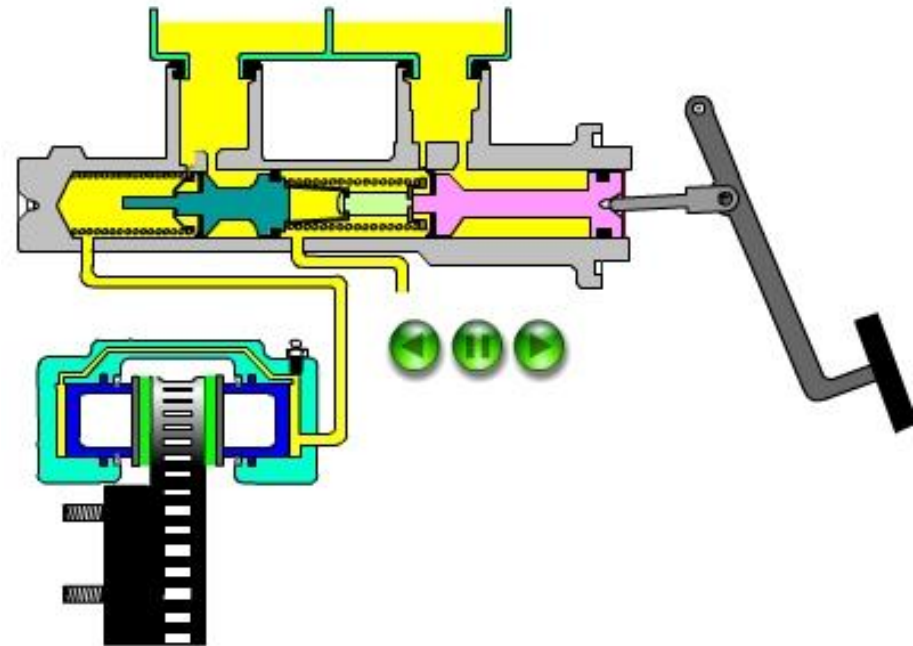
Ventilated disk brakes



# Self adjusting/floating and fixed callipers



Floating calliper disk brake

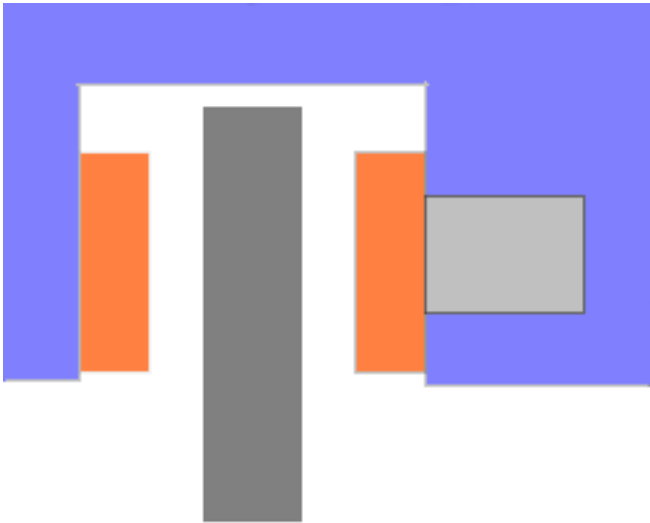


Fixed calliper disk brake

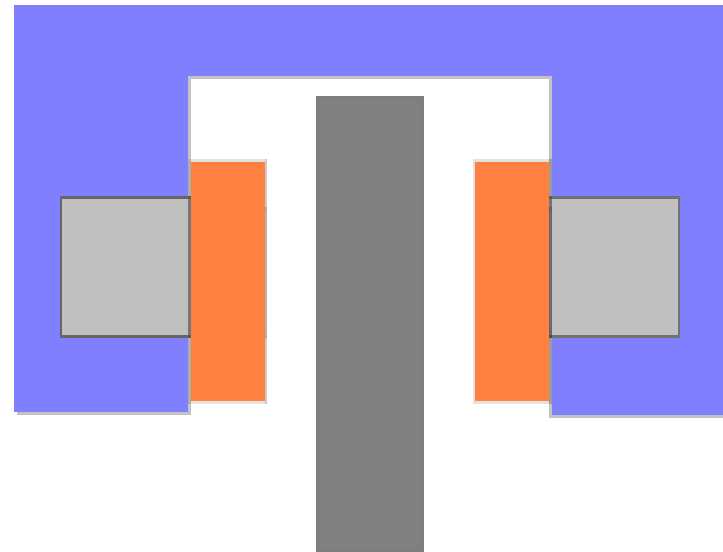


## Self adjusting and fixed callipers

---

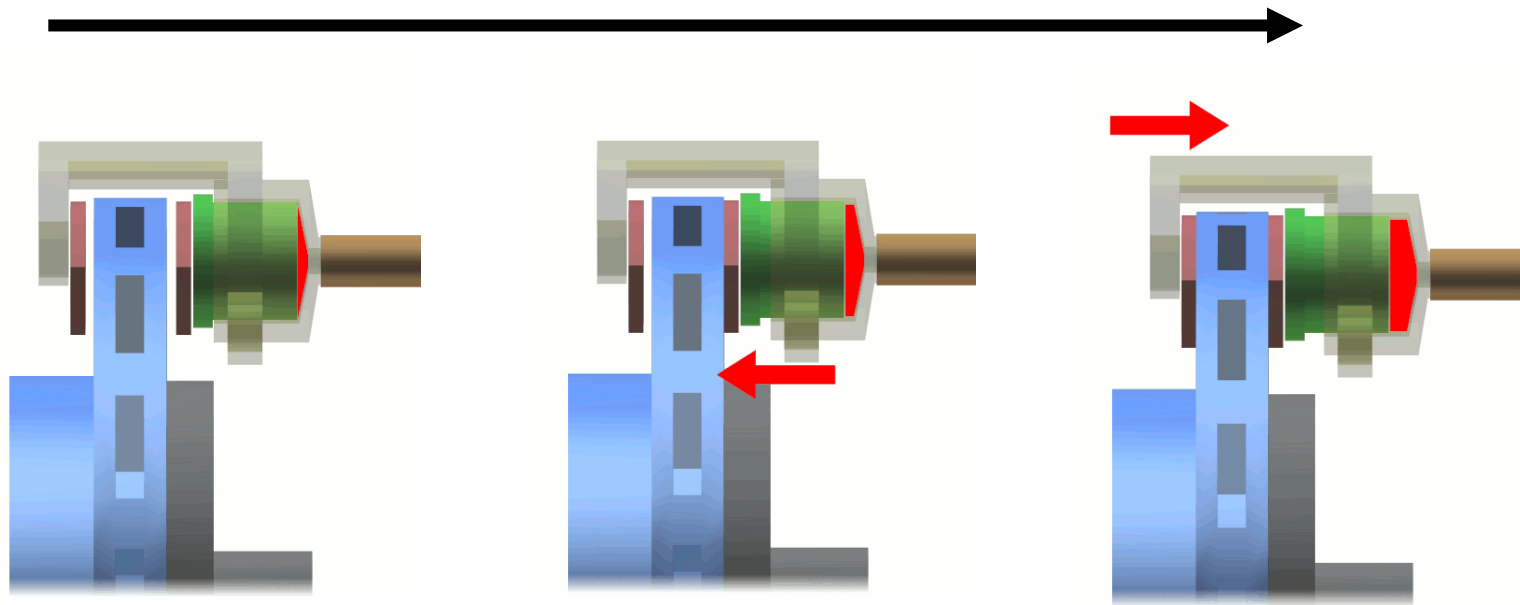


Floating calliper disk brake



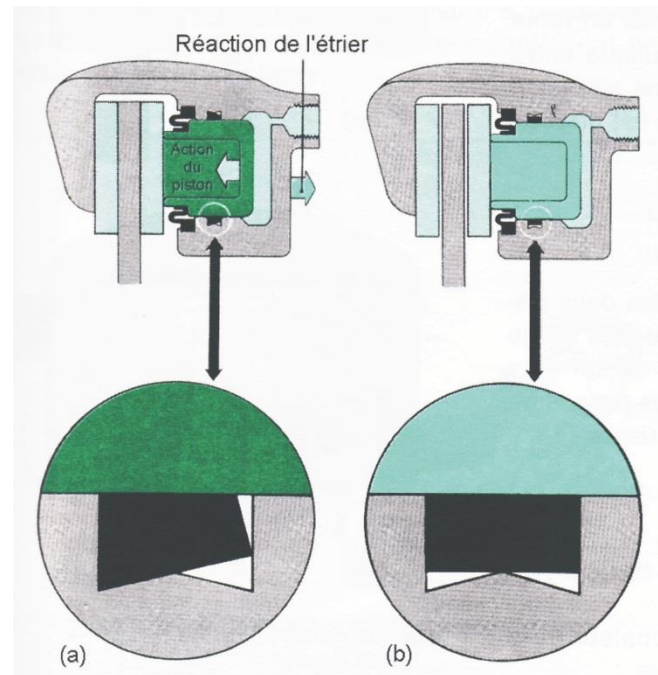
Fixed calliper disk brake

# Self adjusting callipers



Operating principle of floating calliper

# Floating calliper with adjustment



Adjustment mechanism for a floating calliper



## Brake pads

---

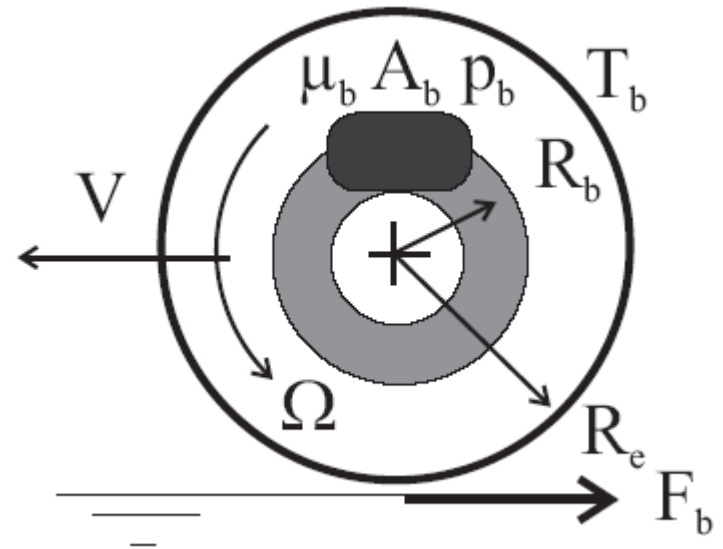
- The pads must resist to high temperature (about 600°C to 700°C) and to important efforts
- The pads are made of high friction materials with friction coefficient in between 0,25 and 0,5
- The pads must:
  - Preserve their high friction coefficient independently of the speed, of the contact pressure, and of the temperature.
  - Resist to the wear without attacking the disk
  - Do not produce stick-slip behaviour and noise
  - Recover their friction properties after being wet
- The reduction of the efficiency of pad materials with the temperature is known as the **fading**. It can conduct to the loss of braking.

## Disk braking factor

- The braking factor of a disk brake

$$\begin{aligned} T_B &= F_B R_e = R_b \mu_b A_b p_b \\ &= R_e k_b p_b \end{aligned}$$

$$k_b = \mu_b A_b R_b / R_e$$





# Drum brakes v.s. disk brakes

---

## DRUM BRAKES

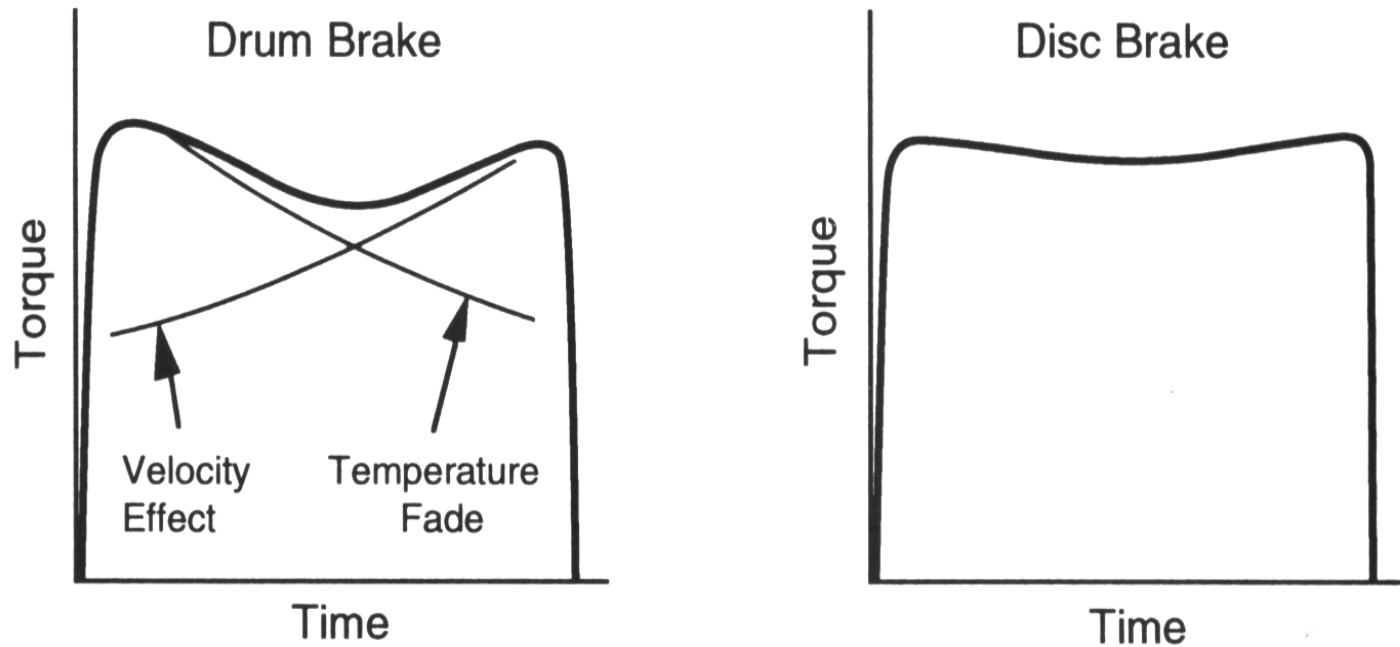
- High braking factor and so low braking actuation effort
- Drawback of the high braking factor: sensitivity of the friction coefficient of the pads can lead to chattering and vibrations
- Braking torque variation with time
- Difficulty to maintain a good braking balance
- Stopping distance can be longer

## DISK BRAKES

- Lower braking factor and so higher braking effort
- More constant brake torque
- Braking torque rather constant
- Better braking distribution
- Stopping distance is lower

## Drum brakes v.s. disk brakes

$$T_b = f(P_a, \text{speed } \omega, \text{temperature } \theta)$$



Gillespie: Fig. 3.3 : Measurement of brake torque for drum brakes and disk brakes on a braking dynamometer



# BRAKING SYSTEM

---



# Command and actuation of the braking system

---

- In a braking system, one must distinguish:
  - The **braking device** itself that is the drum and disk brakes
  - The **command and actuation system** that encompasses all the actuation components of the brakes and their command devices
  
- Specifications of the braking system:
  - Short response time
  - Smooth and precise control force by the driver
  - Requires a moderate actuation effort from the driver
  - Braking distribution is preserved between the two wheels of a same axle, whatever could be the orientation and the motion of the wheels
  - Distribution of the braking forces between front and rear axles as a function of the vertical loads
  - To be able to stop the vehicle even in case of mal function of the braking circuit

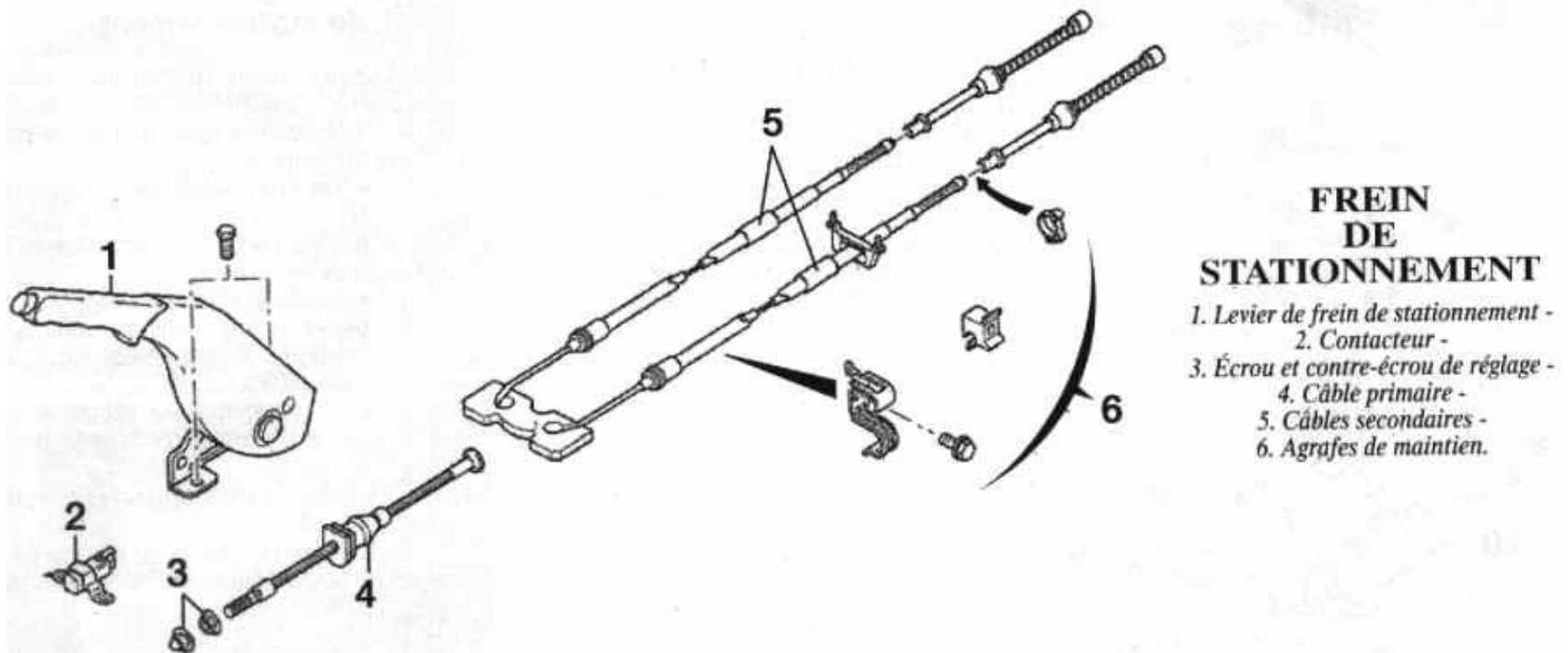


# Command and actuation of the braking system

---

- Types of actuations for a braking system:
  - Mechanical actuation using rigid rods or soft cables (Bowden cables)
  - Hydraulic actuation
  - Pneumatic actuation (mostly used on industrial vehicles)
- For all vehicles, the ECE regulation prescribes to have two different braking actuation systems on board. They must be able to work independently.
- For passenger cars, we have generally:
  - A mechanical actuation system for the emergency brake and the parking brake called hand brake
  - A hydraulic braking system for the main braking system

# Command and actuation of the braking system



Emergency and parking brakes of the Ford Focus 2000

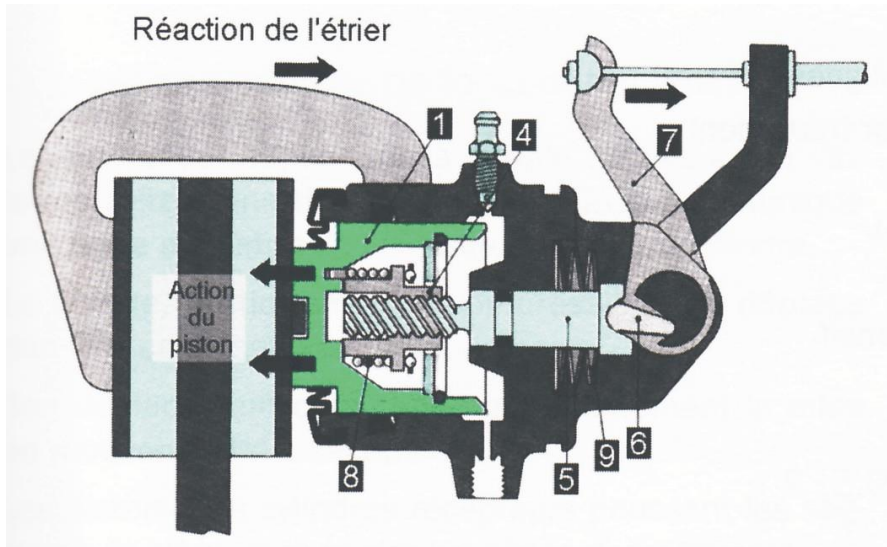


# Command and actuation of the braking system

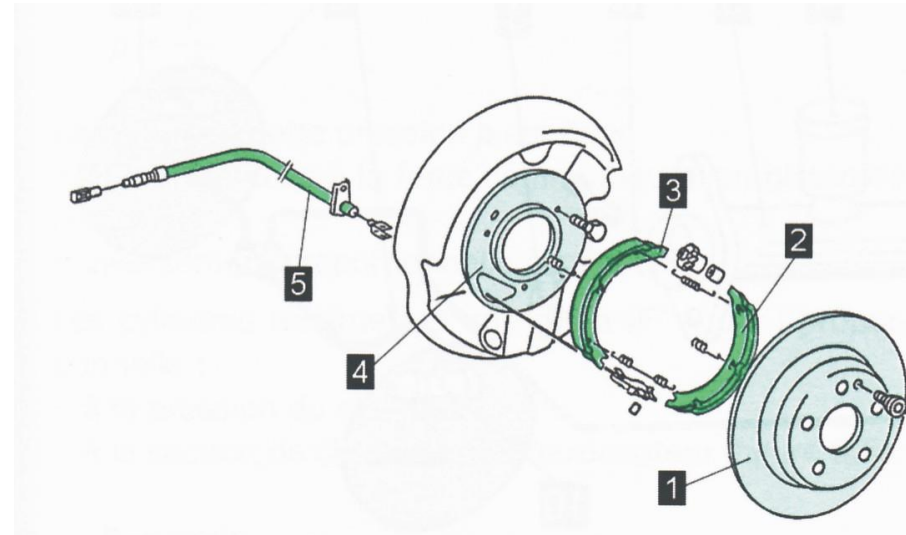
---

- Function of the emergency and parking brake
  - In case of malfunction, it must be able to stop the vehicle within good conditions (to be defined)
  - When stopped, the system must be able to **maintain the permanent standstill conditions**
- The parking system generally acts only on a single axle
- The emergency and parking braking system can (it is not mandatory):
  - Be integrated into the drum brakes
  - Be integrated in the calipers
  - Include some independent calipers with their proper set of pads
  - Be present as a small drum brake system integrated in the disk bowl

# Command and actuation of the braking system



Mémeteau Fig. 9.3  
Parking brake integrated in a  
disk brake



Mémeteau Fig. 9.4  
Drum parking brake in  
a disk brake



## Parking brake systems

---

- Generally, a mechanical actuation is sufficient for emergency and parking brakes:
  - The system is independent of the main brake system (hydraulic or pneumatic)
  - Keep a constant effectiveness even for long parking periods
- The drawbacks of the mechanical actuation systems are:
  - Bad distribution of the braking force on the axles or even between different axles
  - Bad braking stability during suspension jounce/bounce, wheel steering because the system is based on straight lines mechanical components (cables, rods)
  - Low mechanical efficiency because of the various internal frictions
  - Risks of seizure
  - Wear and elongation of the cables
  - Progressive failure of the cables by progressive failure of the filaments

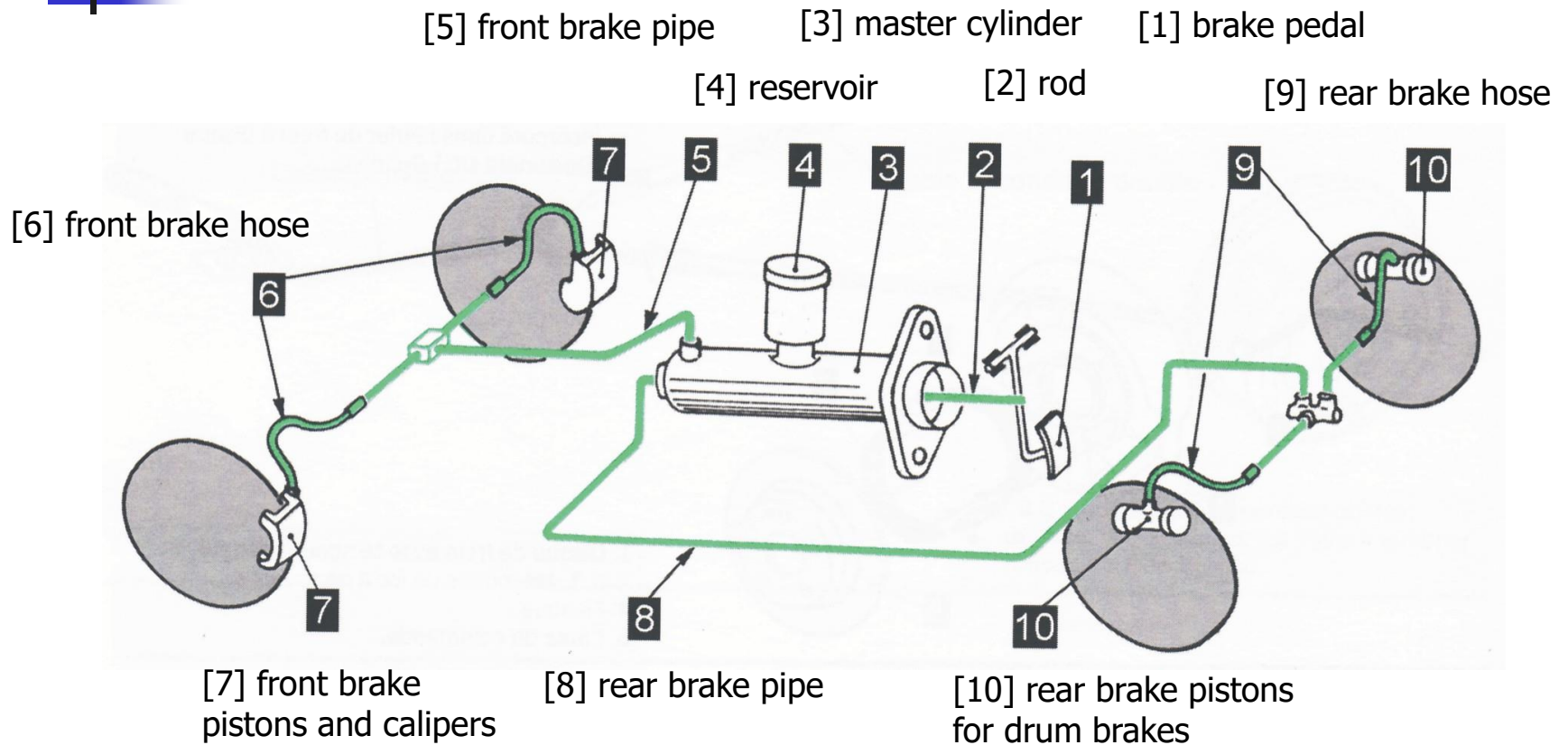


# Hydraulic actuation system

---

- A hydraulic command system includes:
  - A **reservoir** of hydraulic liquid
  - A power source or a **master cylinder** that transforms the brake pedal pressure in hydraulic energy
  - **Receivers**: that convert the hydraulic energy into actuating force of the shoes or of friction pads.
  - A **network of hydraulic pipes** connecting the source to the receivers.

# Basic hydraulic system



Mémeteau Fig. 9.3 Basic hydraulic command system

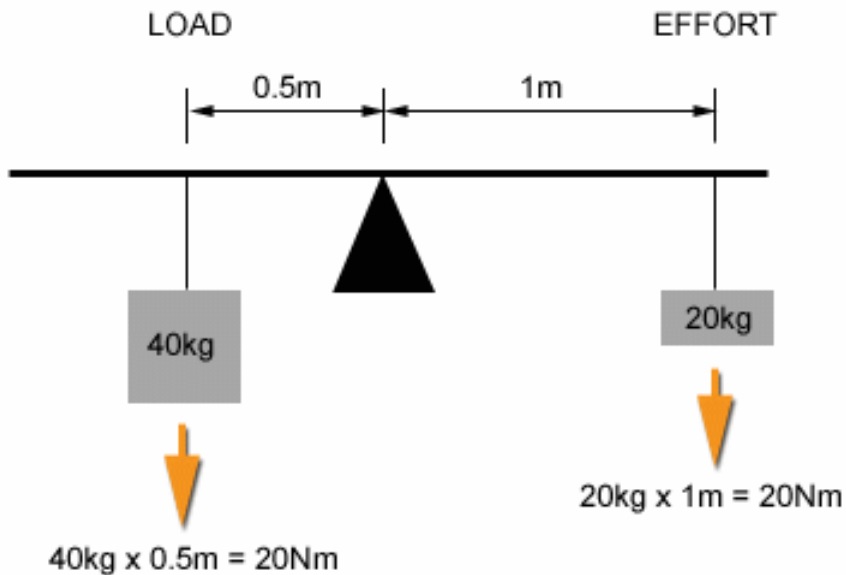


# Hydraulic actuation system

---

- Advantages of hydraulic systems:
  - Perfect repartition of the braking force to the wheels of an axle (the pressure is equal everywhere because of Pascal's principle)
  - Possible amplification of the force when using with different piston sections in the master cylinder and in the brake pistons
  - The pipes can bend and adapt easily the tortuous links
  - The friction is very weak
- The force amplification mechanism in the braking system results from:
  - Mechanical amplification, by a system of levers
  - Hydraulic amplification by using different section ratio

# Force amplification mechanisms

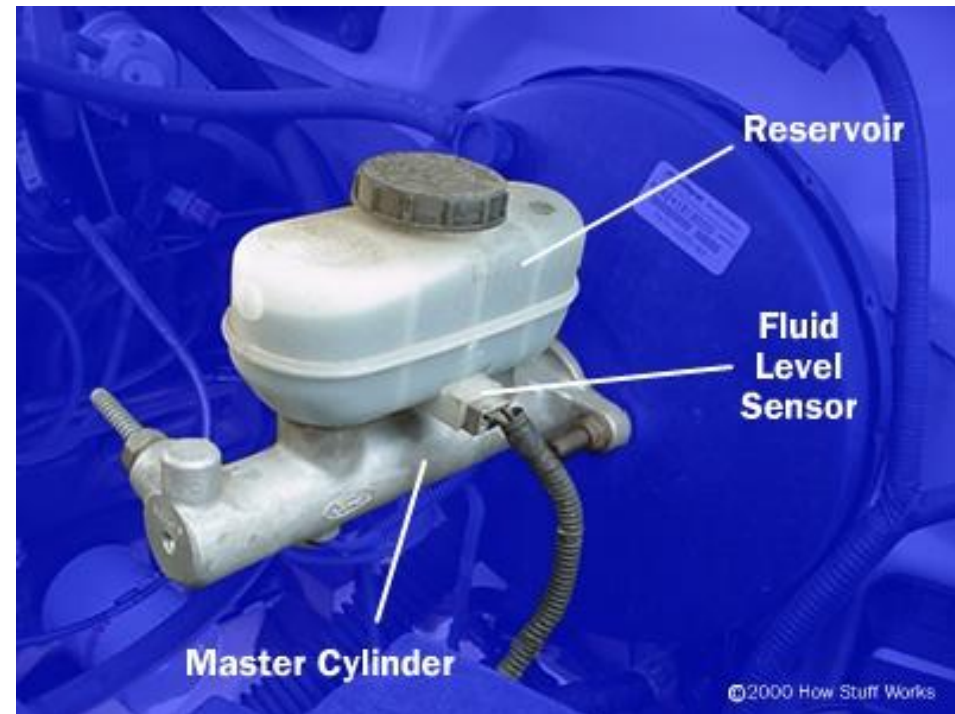
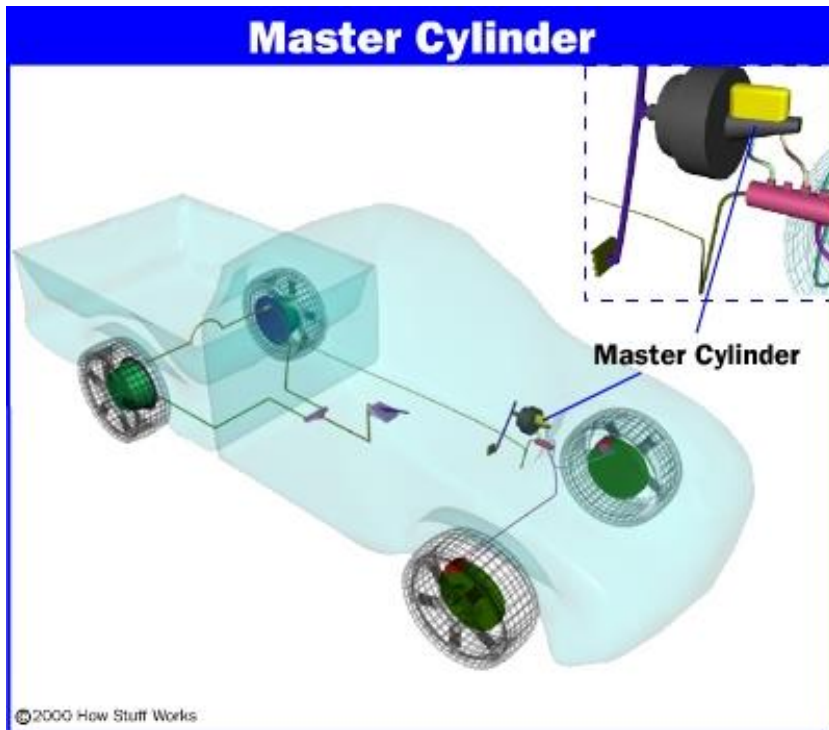


Lever systems

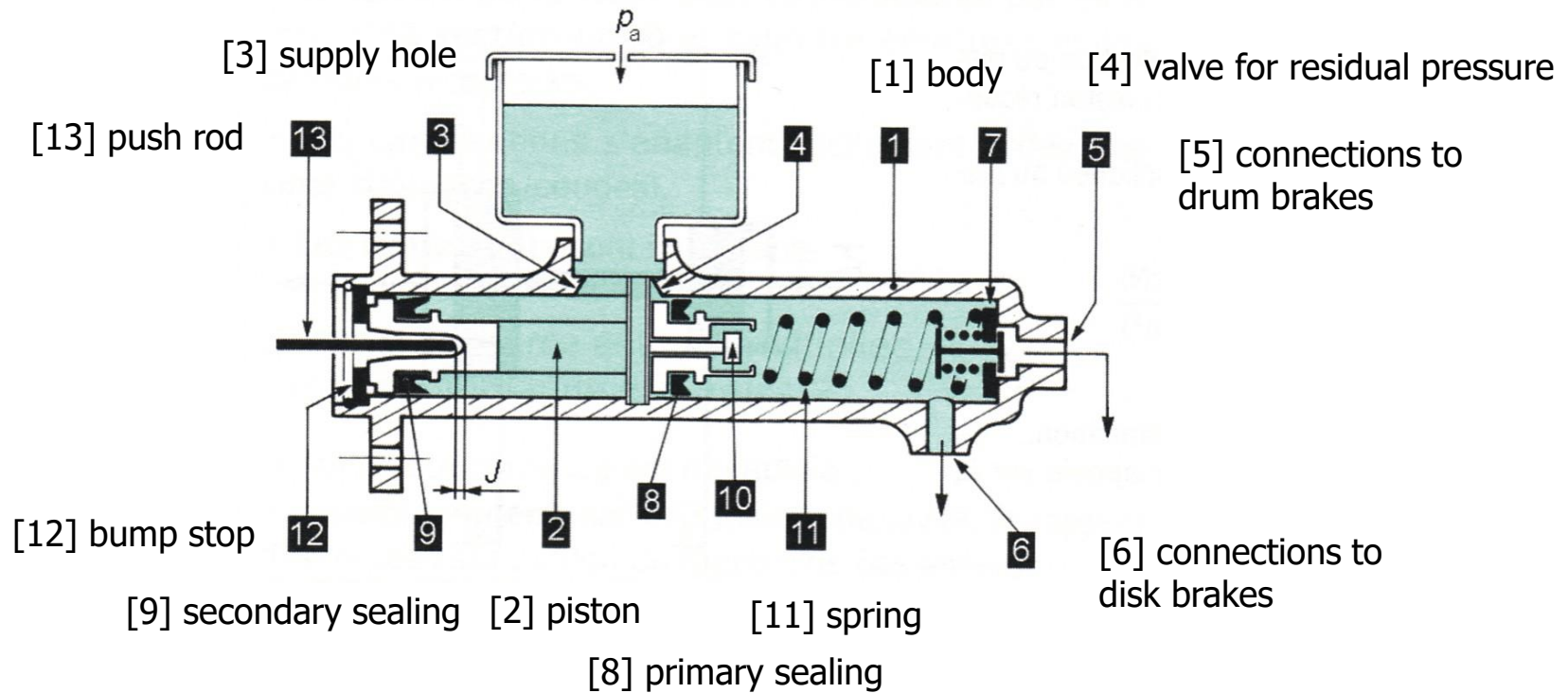


Hydraulic system with different pistons surfaces

# Master cylinder



# Master cylinder



Mèmeteau Fig. 9.9: Single master cylinder



# Master cylinder

---

- Components of the **master cylinder**:
  - A **cylindrical body** [1] communicating with the **reservoir** by an opening in which there is fit slotted elastic pin
  - At the front end, **one or several holes** [5,6] communicating with the pipes to the receiving brake cylinders
  - A **valve for the residual pressure** [7] for the drum disks hydraulic circuits
  - A **piston** sliding [2] in the cylinder bore
  - A second ring that insure the **sealing** [9] with respect to outer
  - A **spring** [11] for the **recall of the piston** that keeps the pressure valve and the primary cups



## Double braking circuits

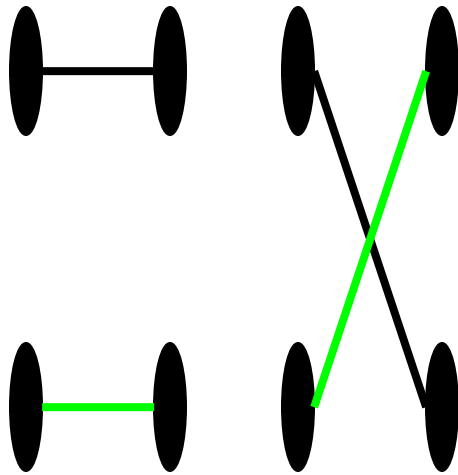
---

- Requirement for a **double braking circuit**:
  - If the four receiving pistons are connected to a single network of pipes and to the master cylinder,
  - In case of leakage, the pressure drops everywhere in the pipe network coming to a total failure of the braking system
  - With a double braking circuit, one increases the safety and the reliability of the system because some braking capability is preserved in case of leakage in one network.
  
- Double braking circuit implies:
  - A tandem master cylinder
  - Two reservoirs
  - Two pistons (primary and secondary ones)
  - Two independent networks of pipes

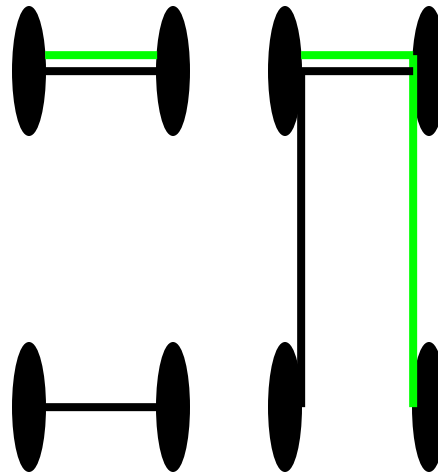


## Double braking circuits

---



One circuit for two wheels:  
Parallel or cross lay-out

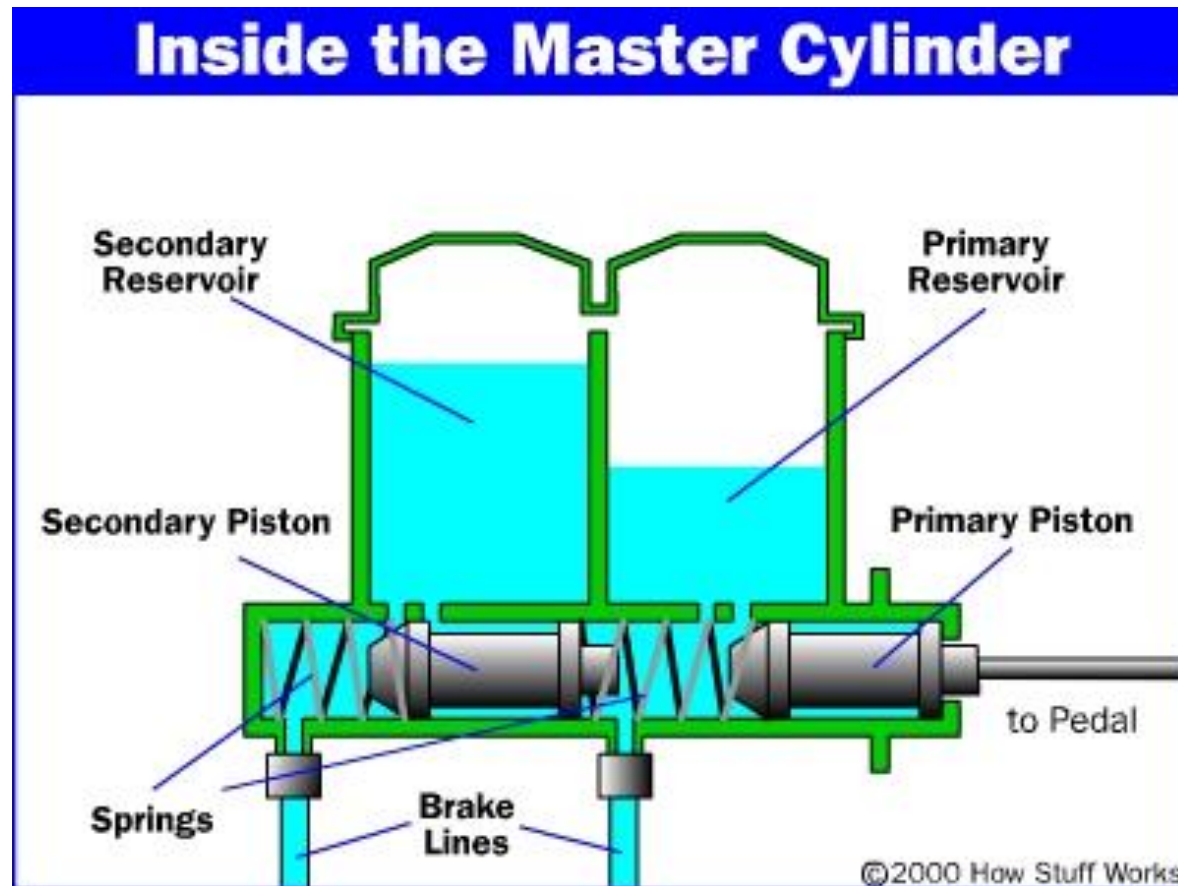


Front circuit is doubled:  
Parallel or triangular lay  
out



Completely doubled  
circuit

# Tandem master cylinder



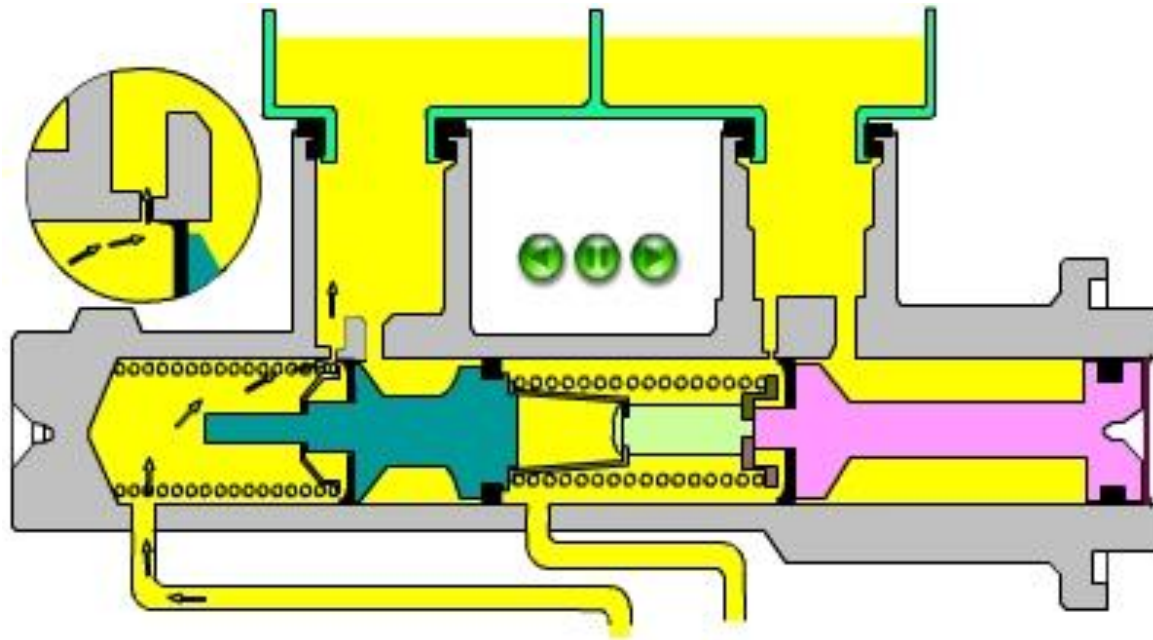


## Tandem master cylinder

---

- Normal operation of a tandem master cylinder
  - When the brake pedal is depressed, the rod is pushed and then is pushes the primary piston
  - The pressure growths in the primary cylinder and the fluid is pushed in the primary circuit.
  - The pressure in the first cylinder acts on the wall of the second piston, and the pressure growths as well in the secondary cylinder and the fluid is also sent into the secondary circuit.
  - In case of normal operation, the pressure is the same in the two circuits.
- In case of leakage, the system keeps on working but with a longer displacement of the brake pedal

## Tandem master cylinder



Working principle of a tandem master cylinder

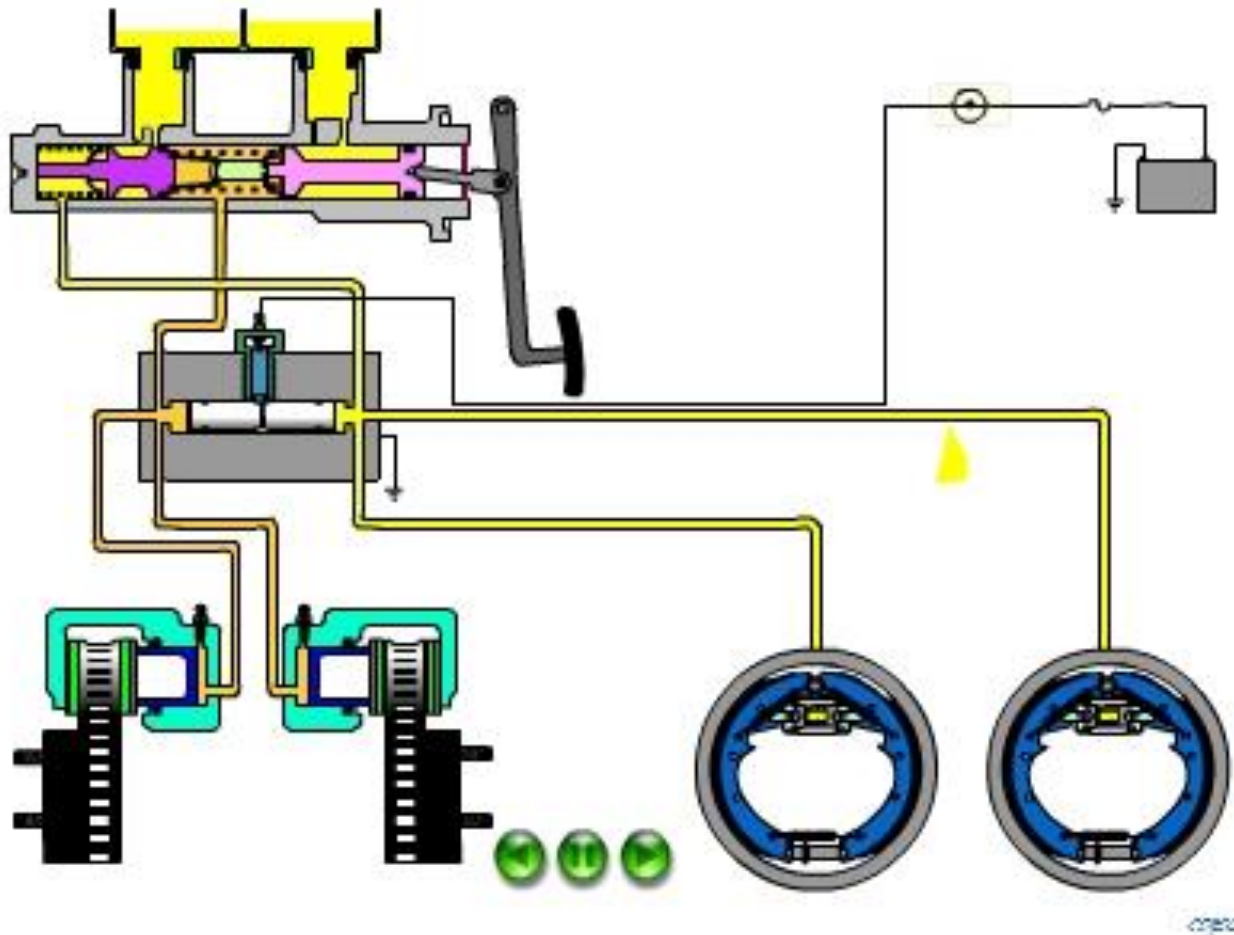


## Tandem master cylinder

---

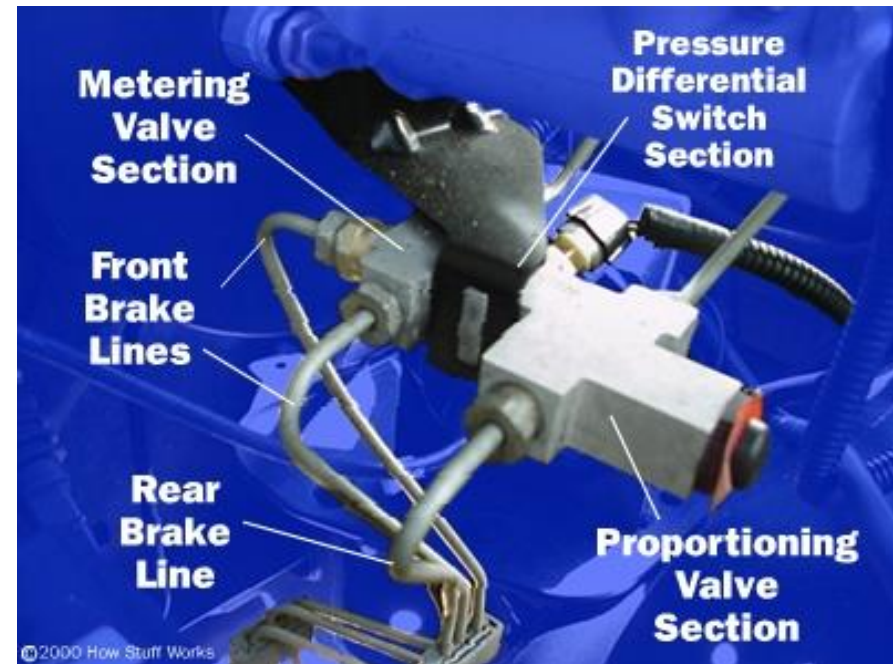
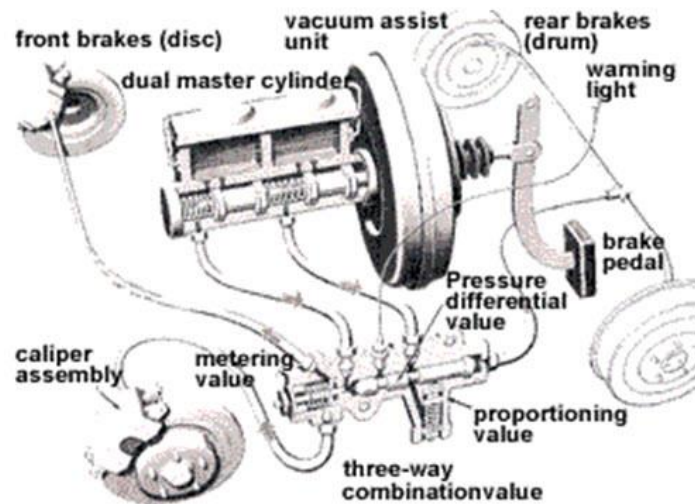
- In case of a leakage, the tandem master cylinder works as following:
  - Let a leakage in circuit 1. The pressure drops between 1 and 2.
  - The piston 1 is pushed without any resistance until coming into contact with the face of the piston 2.
  - When the two pistons are in contact, the system works as a single piston
  - The circuit 2 continues working but the driver feels a longer displacement of the brake pedal to be actuated. This gives a warning feedback signal to the driver.

## Hydraulic circuit in case of a leakage



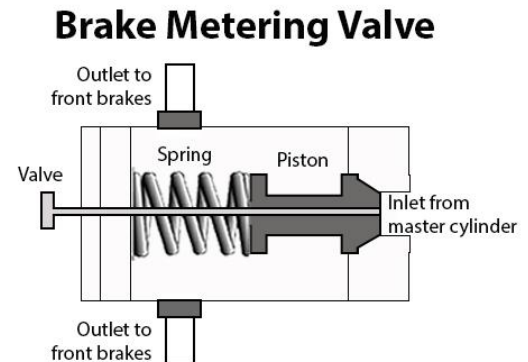
# Combination valve

- The combination valve has three separate functions:
  - Pressure metering valve
  - Pressure differential switch
  - Proportioning valve



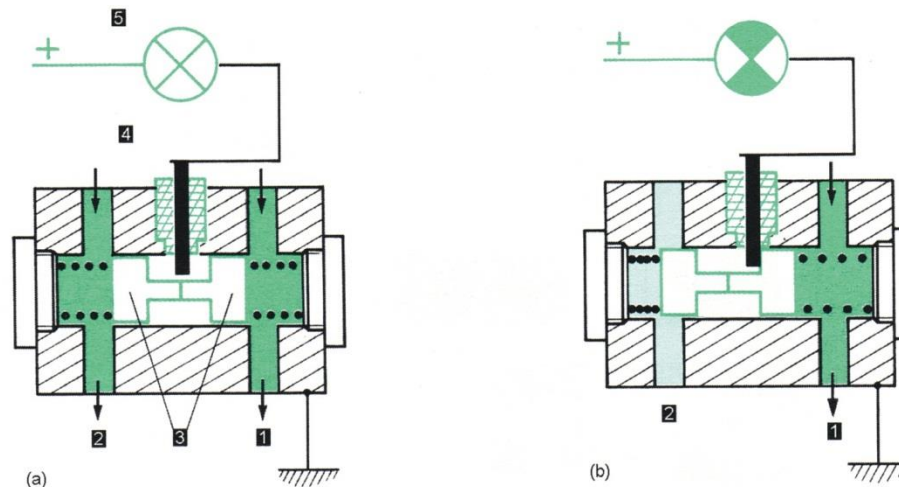
# Pressure metering valve

- The **pressure metering** valve is required for vehicles with both disk brakes in front and drum brakes on the rear axles.
- The brake pads of brake disks are remaining nearly in contact with the disks whereas the shoes in drum brakes are extracted from the drum by a spring elements. Thus the time responses of drum brakes is longer than disk brakes.
- For braking stability, one has to **delay the actuation** of the disk brakes on front wheels.
- The metering valve is a calibrated valve that allows an actuation of the front brake disks after a given threshold of pressure



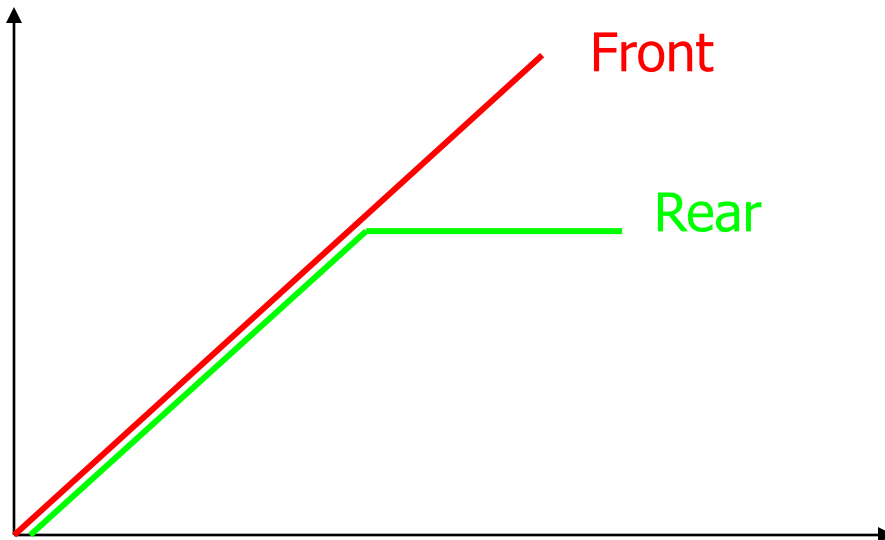
# Pressure differential switch

- The **pressure differential switch** is a device devoted to warn the driver when there is a pressure drop in one of the circuits
- It is made of a small piston whose faces are in contact with the pressure in the two circuits.
- A pressure difference conducts to a displacement of the piston which ensures an electrical contact to switch on a light for the driver

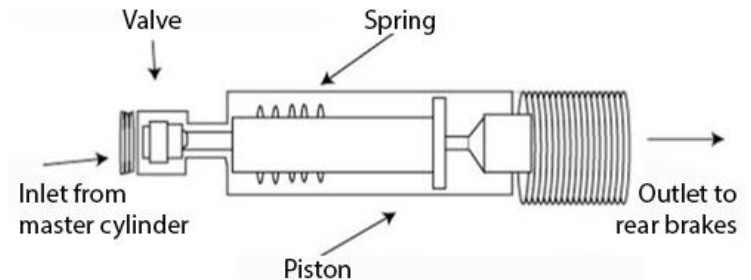


# Proportioning valve and pressure limitation

- The **proportioning valve** is a valve that reduces the pressure in the rear brake pistons to prevent the rear wheel locking in case of severe braking conditions.



## Brake Proportioning Valve





# Braking assistance

---

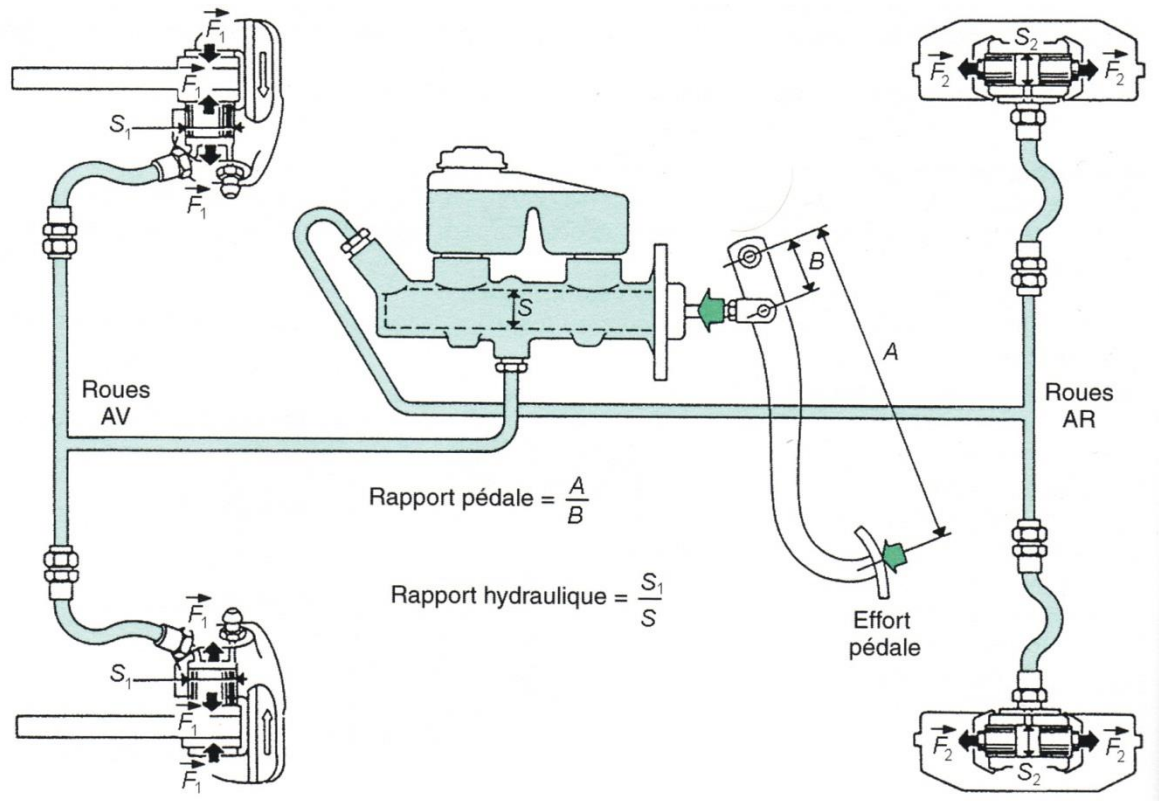


## Braking assistance

---

- **Braking assistance** = device that enables to develop a high pressure in the hydraulic braking circuit with a low or moderate pedal force.
- Devices enabling the braking efforts:
  - Mechanical systems: lever arms
  - Hydraulic systems: different cross sections of the pistons
- Brake assist systems:
  - Magnification of the effort developed without using mechanisms that requires increasing the actuation force with the pedal displacement.

# Braking assistance



Mèmeteau Fig 10.1



# Braking assistance

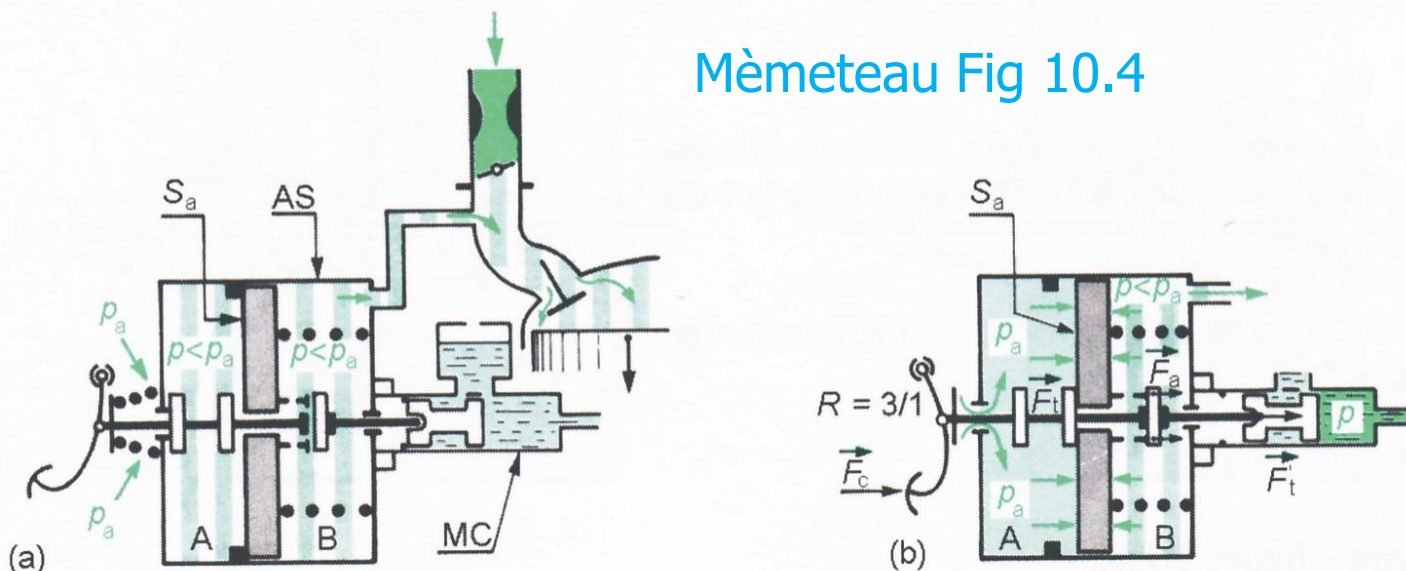
---

- Source of braking assistance:
  - Create a **low pressure** using the pressure loss in the admission manifold (for SI engines) and a vacuum pump (for CI engines)
  - Create a **high pressure** in the hydraulic fluid developed by a hydraulic pump
  - Create a **high pressure** of air developed by a compressor (as in industrial and heavy utility vehicles)
- Assistance is obtained by the action of the difference of pressure across the two faces of a membrane
- The magnitude of the actuating force is the sum of
  - The braking force on the pedal multiplied by the *mechanical advantage* of the pedal
  - The additional force of the assistance device

## Braking assistance

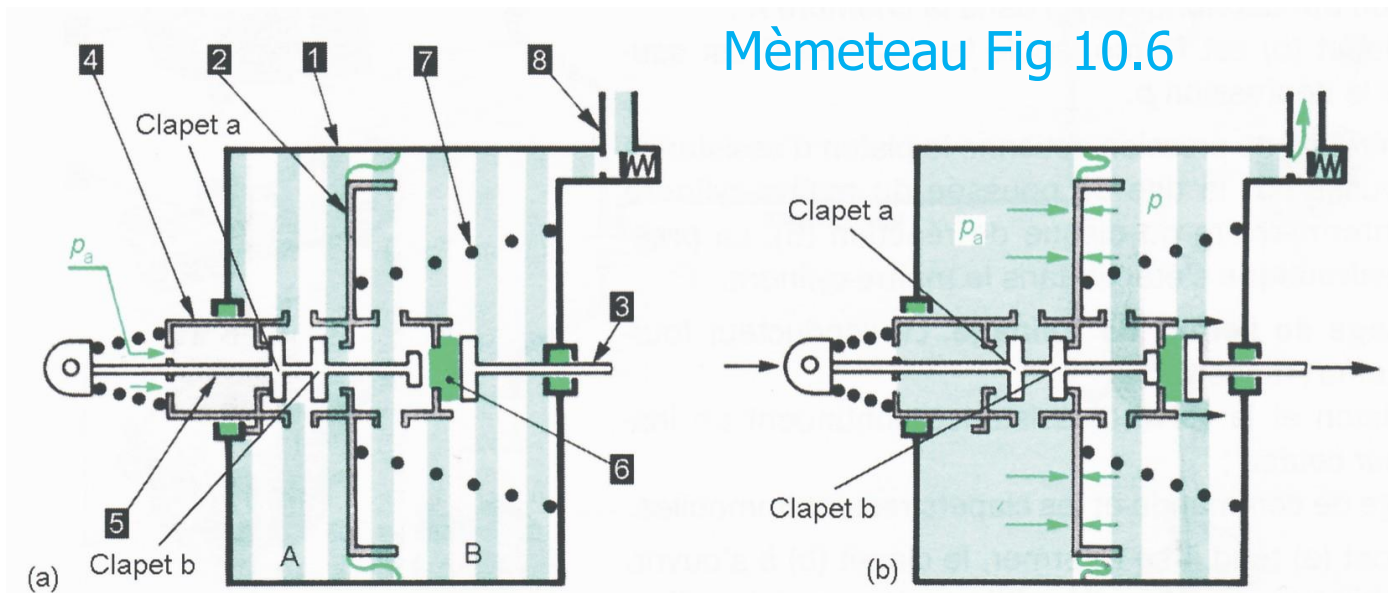
- The pressure loss in the admission manifold (for SI engines) and a vacuum pump (for CI engines) creates a low pressure in the back side of the membrane.
- When brake pedal is depressed, air at ambient pressure is admitted on the front side of the membrane.

Mèmeteau Fig 10.4



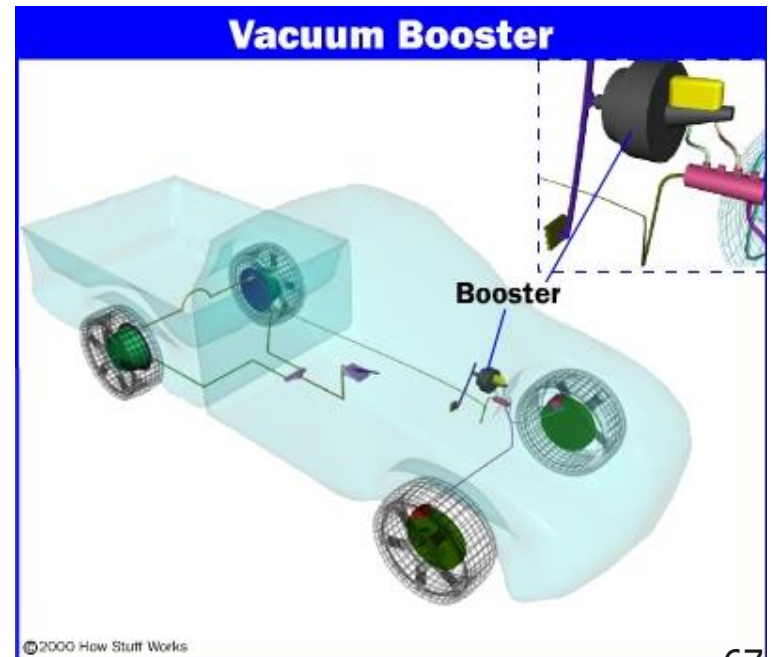
## Braking assistance

- The difference of pressure creates a force onto the membrane that is added to the human actuation force.
- When braking actuation stops, the rod opens the communication channel which establishes vacuum conditions in both side of the membrane



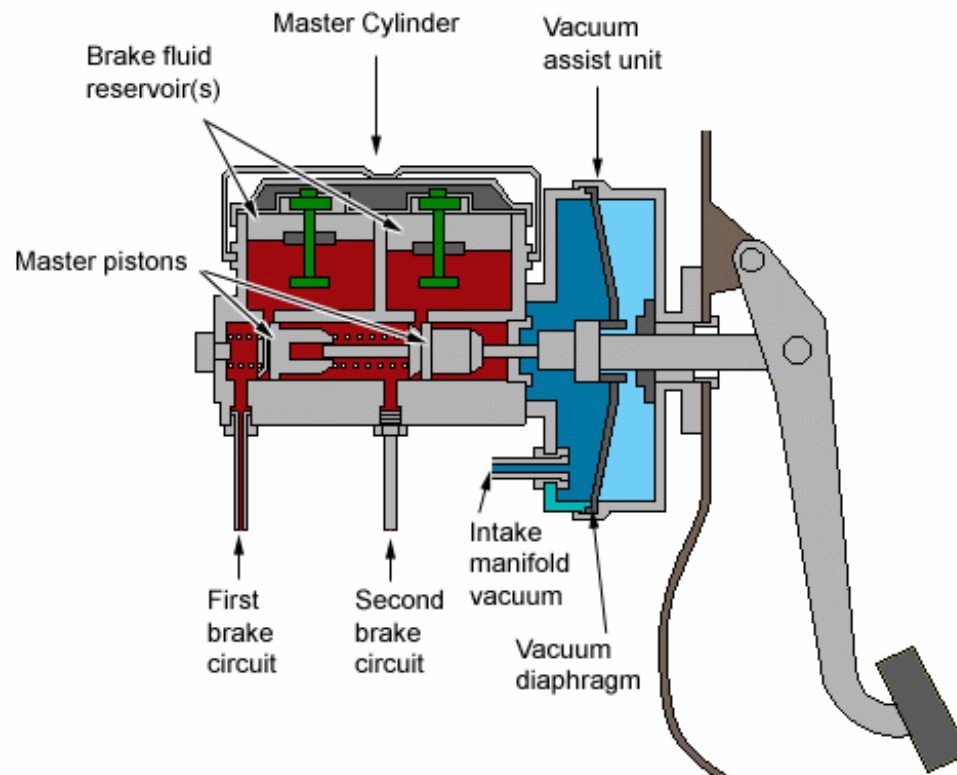
# Braking assistance

- System of braking assistance
  - Hydrovac
  - Master vac



## Vacuum assist unit

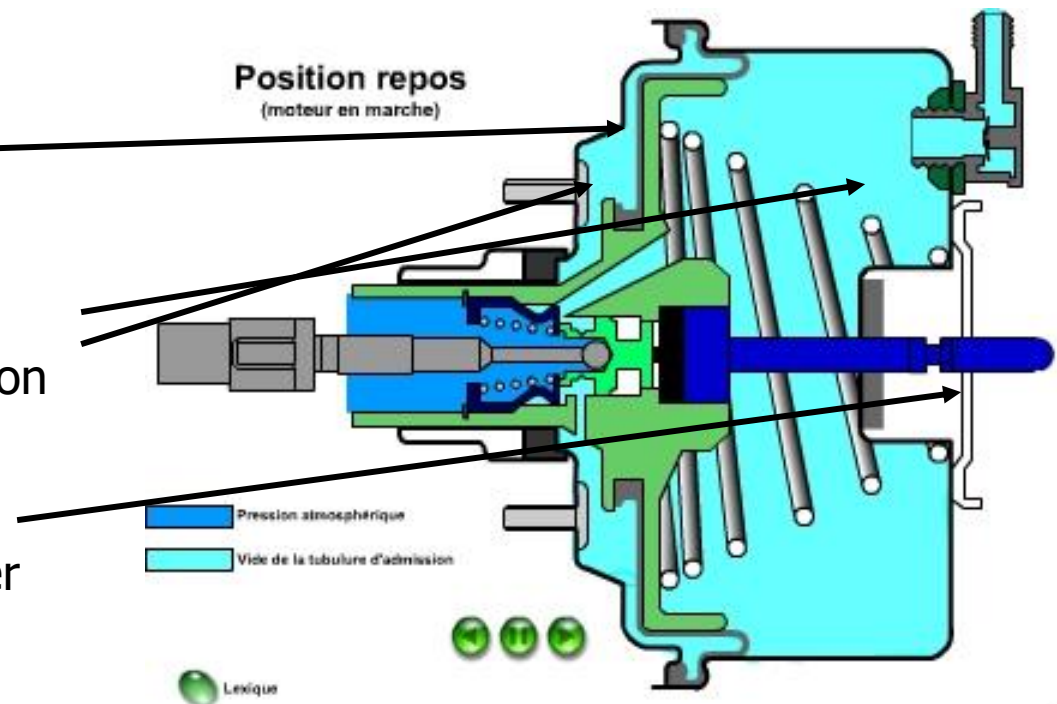
- The **vacuum assist unit** is inserted between the brake pedal and the master cylinder.



# Vacuum assist unit

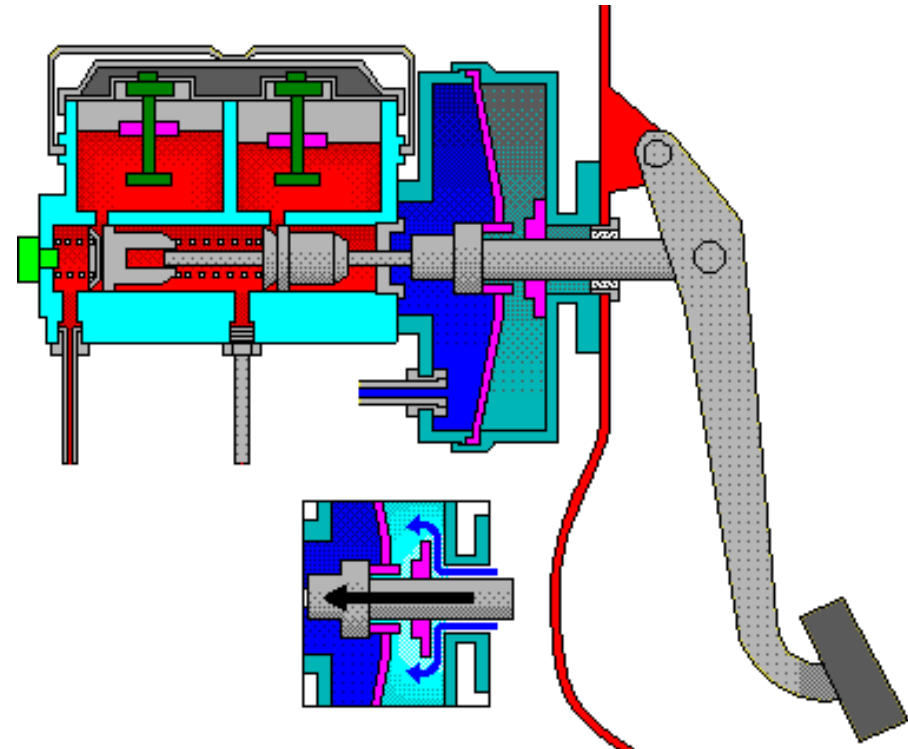
- It includes:

- A cylinder with a large diameter (in green)
- The two chambers are separated by a sliding piston
- The piston pushes the actuation rod of the master cylinder



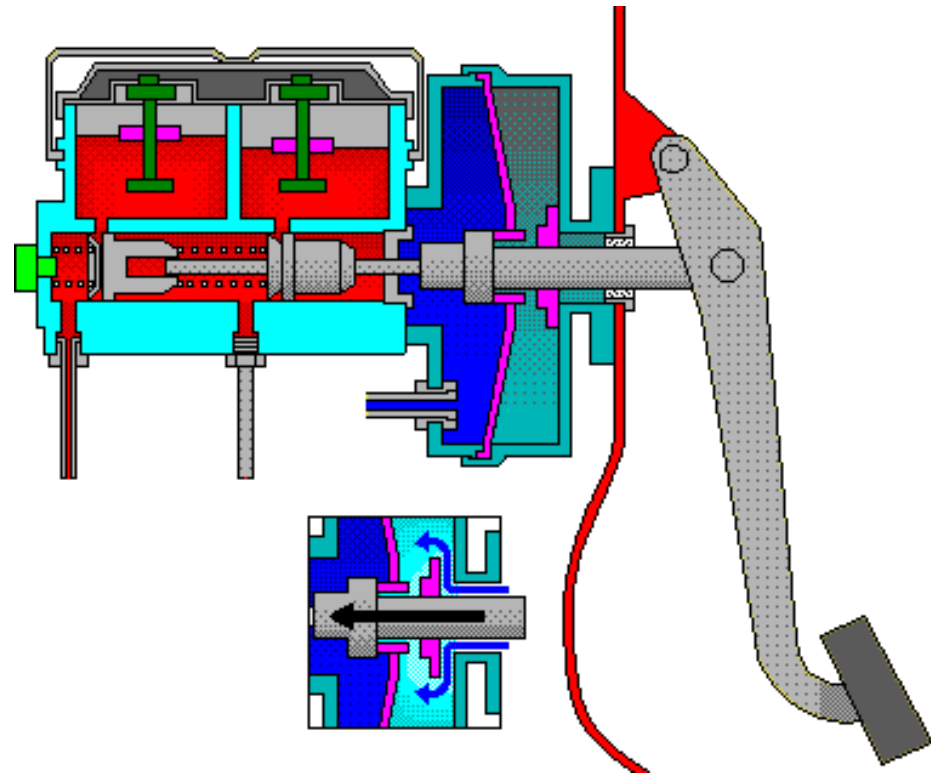
## Master Vac – working principle

- The device uses the low pressure available from engine admission pipes
- When the rod is pressed, the air at atmospheric pressure can enter into contact with the diaphragm in the right-hand side part
- The pressure difference between the two sides of the diaphragm pushes the rod of the master cylinder
- As the pressure difference is rather limited, the diameter of the piston must be large to create a significant force



## Master Vac – working principle

- When the pressure on the braking pedal is relaxed, the atmospheric pressure valve is released
- The right-hand side of the diaphragm is set under depression
- The assistance force is cancelled by returning to initial position



# The check-valve



- The **check-valve** is a one-way valve that allows the low-pressure air to leave the master vac low pressure chamber but not to enter into the master vac
- So in case of pressure leakage or engine stop, or in case of a pressure leakage, it is not allowed to admit atmospheric air into the chamber
- This guarantees that the master is able to work several times and to safely operate an assistance force even if the engine has stopped working



# Summary

---

## Summary: the braking system

[11] piston

[9] master cylinder

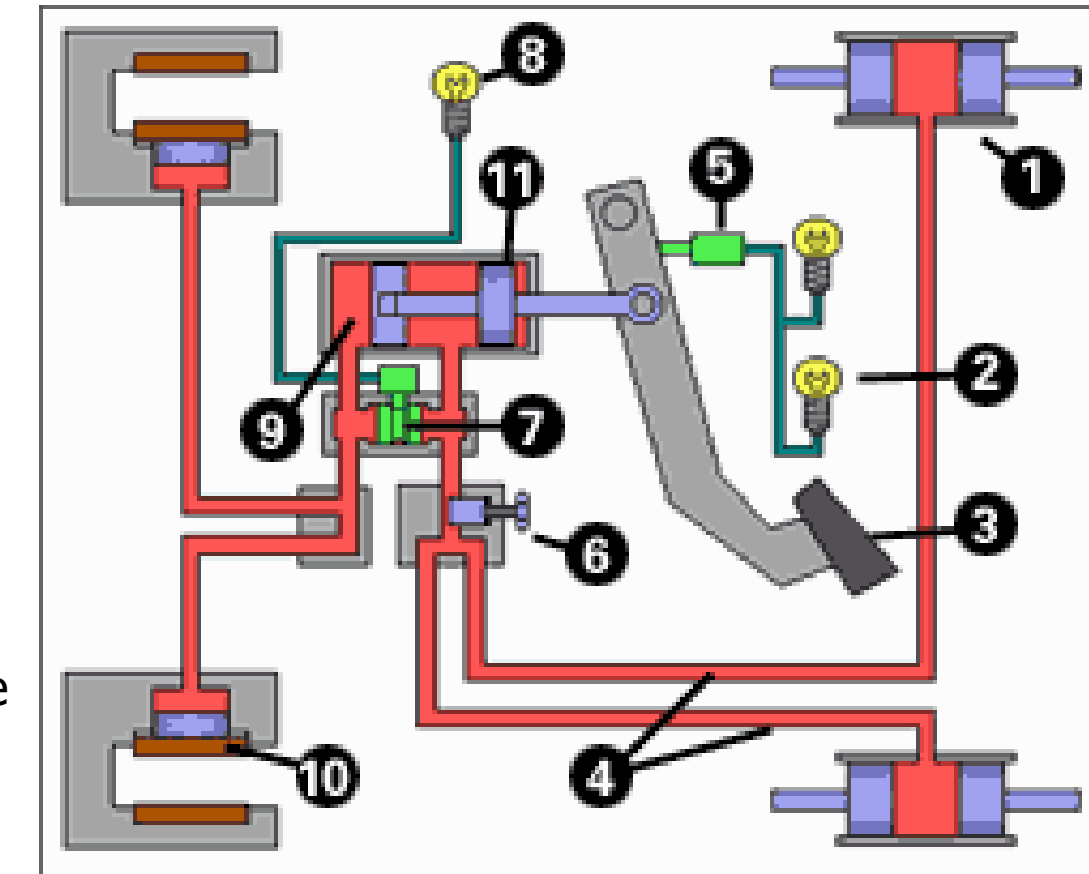
[7] pressure differential switch

[10] front brake pistons of disk brakes

[1] rear brake piston of drum brakes

[2] stop lights

[3] brake pedal



[6] pressure metering

[4] rear brake pipes