Anaesthetic breathing systems link the patient to the common gas outlet of the anaesthetic machine, thereby supplying a source of oxygen, anaesthetic gas / vapour, and a means of removing exhaled carbon dioxide. The different breathing systems vary in their ability to eliminate carbon dioxide during spontaneous and intermittent positive pressure ventilation. Anaesthetic machine have a coaxial male 22 mm, female 15 mm conical connector to the breathing systems.

Classification of breathing systems

Classifications by Conway in the UK, and Dripps in the USA, using the terms open, closed, semi-open and semi-closed, differ in definition, are confusing, and are not discussed further.

The best and most comprehensive classification of breathing systems is that developed by South African trained anaesthetist, Dr Don Miller who devised a classification of breathing systems based on their structure and function.

Classification of breathing systems after Miller 1,2

Breathing systems are divided into two broad classes depending on whether they absorb carbon dioxide or not.

Further subdivision depends on whether flow in the breathing system is unidirectional or bidirectional. Bidirectional flow systems are further subdivided into afferent and efferent and junctional reservoir systems. Afferent tubes supply fresh gas from the anaesthetic machine to the patient and require a reservoir in the afferent limb hence the term afferent reservoir system. Efferent tubes carry predominantly expired gas from the patient to the exhaust valve. Junctional reservoir systems (such as the Magill B or C have a reservoir bag close to the junction of the afferent and efferent tubes.

The individual systems in each subgroup have similar fresh gas flow requirements and performance characteristics.

1. Systems with absorption of carbon dioxide

   (i) Unidirectional flow – circle system (Kuhn, Sword (1930))

   (ii) Bidirectional flow – To-and-fro cannister (Waters 1924)

2. Systems without absorption of carbon dioxide

   (i) Unidirectional flow
      (a) Non rebreathing valves (Rubin, Laerdal, Fink, Ambu)
      (b) Circle system (Eger and Ethans)

   (ii) Bidirectional flow
      (a) Simple afferent reservoir (Magill, Lack, Miller)
      (b) Enclosed afferent reservoir (Miller & Miller 1988)
      (c) Junctional reservoir (Mapleson B and C)
      (d) Efferent reservoir (Bain, Mapleson D, E, F)
The following systems for providing inhalational anaesthesia will be discussed.

**Insufflation**
The blowing of anaesthetic gases across a patient’s face using a mask is sometimes used for induction of anaesthesia, particularly in paediatric practice in patients resisting the placement of a mask on their face. The inspired concentration from this technique is unknown.

**Draw-over anaesthesia systems**
Simple portable, draw over systems have found use in resource strapped hospitals where gas supplies are unreliable, and in military conflict zones such as in the Falklands war and in Iraq. In draw-over systems air or oxygen enriched air is drawn through a low resistance vaporizer by the patient’s inspiratory effort. An AMBU type valve providing one way flow of gases is necessary to prevent rebreathing. Examples of suitable vaporisers are the EMO ether vaporiser, and the Tri-service apparatus using in series halothane and trichloroethylene PAC vaporisers and the Ohmeda Universal Portable Anaesthetic Complete Apparatus (U-PAC) used by US forces in Iraq.

Problems include limited control of anaesthetic concentration and theatre pollution.

![Image of Triservice anaesthetic apparatus](Image from Out of our comfort zone: Pain relief in a crisis, display at the AAGBI History of Anaesthesia Museum)

**Mapleson Breathing Systems**
In 1954 Mapleson described and analysed the performance characteristics of five different semi-closed anaesthetic systems that are categorized from A-E. A sixth system, the Mapleson F was added later. (Fig. 2)

![Mapleson classification of breathing systems](Fig. 2 Mapleson classification of breathing systems)
Mapleson A (Magill system)
Designed by Ivor Magill in 1928 this afferent reservoir system was widely used, and is still used today particularly in rural hospitals. It consists of a 3-way T-tube connected to the fresh gas outlet, a breathing bag, a reservoir tube connecting to the patient, and a adjustable spring-loaded expiratory valve at the patient end. It is the most efficient Mapleson breathing system for spontaneous ventilation because it conserves exhaled dead space gas and vents exhaled alveolar gas provided fresh gas flows of 70 ml/kg are utilised. It is inefficient for controlled ventilation requiring high gas flows (2-3 x minute volume), to prevent rebreathing.
The system is also difficult to scavenge. A co-axial version was designed by Lack in 1976.

Mapleson B and C breathing systems are classified as junctional reservoir systems. Mapleson B systems are obsolete. Mapleson C systems are not used for anaesthesia but are still used in some hospitals for resuscitation and for short-term transport.

Mapleson D
This system is inefficient for spontaneous ventilation because unless gas flows are very high, exhaled gas enters the reservoir bag together with fresh gas. It is efficient for IPPV at a flow rate of fresh gas of 70 ml/kg/min because exhaled dead space gas passes into the reservoir bag together with fresh gas so that the reservoir bag is full by the time that alveolar gas reaches the bag. Alveolar gas is thus vented via the expiratory valve.
The Bain circuit (1972) is a popular co-axial form of the Mapleson D that allows easy control of the expiratory valve, and scavenging. Another advantage is that because the fresh gas flow is delivered at the patient end, the tubing can be longer than the standard Magill system without increasing dead space and can therefore be used to provide anaesthesia from a safe distance for MRI.
Disconnection, kinking or leaks of the inner gas supply tube can result in significant breathing of exhaled gas.
The following checks should be performed before using a Bain circuit:

- Visual inspection of the inner and outer tube looking for leaks or disconnection of inner tube.
- Occlusion test (described by Foex and Crampton-Smith in 1977). After connecting Bain circuit to the common gas outlet, switch O₂ flow to 2 L/min¹ and then occlude the inner tube with the plunger from a 2ml syringe. If there is no leak then the flow meter bobbin will drop slightly due to increased back pressure. On release it will return to its original position.
- Ghani’s test (1984) – a modification of the occlusion test: after connecting the Bain circuit to the common gas outlet of the anaesthetic machine, switch on flow of oxygen at 2 L/min¹, then occlude the inner tube with the tip of a plunger of a 3 ml syringe. On releasing the plunger tip a hissing sound lasting 2-3 seconds should occur due to release of pressure in the inner tube. This will not occur if there is a hole in the inner tube.
- Pethick’s oxygen flush test – After connecting the Bain circuit to the common gas outlet, fill the reservoir bag with oxygen and then flush the circuit using the oxygen flush button. If there is no leak then the reservoir bag will collapse due to the Venturi effect.

Mapleson E (Ayre’s T piece)
Dr Phillip Ayre designed this low resistance breathing system for use in paediatric anaesthesia in 1937. A fresh gas flow of 2-3x minute volume is required to prevent rebreathing. To prevent dilution of anaesthetic gases with room air, the volume of the efferent reservoir limb should exceed tidal volume.
Ventilation could be achieved by intermittent occlusion of the reservoir limb outlet. Disadvantages included difficulties in scavenging and humidifying gases. The Cape Town and other breathing systems were developed to reduce the dead space when anaesthetising a child using a mask with the Ayre’s T piece.

Fig. 3 Top – Ayres T-piece with endotracheal tube and Cape Town breathing system that reduced dead space
Mapleson F (Jackson Rees - 1950)
Jackson Rees modified the Mapleson E by adding an open-ended 500 ml bag to the expiratory limb allowing easier manual ventilation and the ability to monitor respiration by observing movements of the bag. Suggested FGF’s of 23 x minute volume for spontaneous ventilation and 200 ml / kg for IPPV were recommended.

The Humphrey ADE system, designed by Durban anaesthetist and physiologist, David Humphrey in 1981, allows users to choose between using the system in the A, D or E mode and is suitable for use in paediatric, adult and veterinary anaesthesia. Later modification added a soda lime canister.

Systems with carbon dioxide absorption
The idea of using substances to absorb carbon dioxide in breathing systems was known by the early anaesthetists, including Englishman, Dr John Snow. Ralph Waters in Wisconsin popularized the use of soda lime to absorb CO₂ in his Waters to-and-fro canister in 1924. (Waters became the world’s first Professor of Anaesthesia). The canister provided excellent humidification and warming of gases, reduced the cost and risk of explosion with expensive gases combustible gases such as cyclopropane. The apparatus was heavy and bulky, and if the canister was not filled with absorbent would allow channeling to occur. The latter problem was solved by Johannesburg anaesthetist Hymie Samson who designed a see through casing for the absorbent that allowed visual inspection of the absorbent and the use of indicator dyes to demonstrate when the soda lime was no longer absorbing CO₂.

![Fig. 4 Waters to-and-fro canister modified by Samson](image)

Circle Breathing System
The circle breathing system, using soda lime to absorb carbon dioxide is the most popular breathing system currently in use. The earliest system of this type was developed by Carl Gauss in 1925 and manufactured by Drägerwerk of Lübeck, Germany. American Brian Sword popularised the circle system in the English-speaking world in 1930.

It consists of seven components: (1) A fresh gas inlet from the common gas outlet of the anaesthetic machine, (2) inspiratory and expiratory corrugated tubing, (3) inspiratory and expiratory valves, (4) a canister containing carbon dioxide absorbent, (5) a reservoir bag, (6) an adjustable pressure limiting (APL) valve, and (7) a Y-piece connector. Modern circle systems also have a bag/ventilator switch and a ventilator that is usually either a piston driven ventilator (Dräger) or an ascending bellows.
For optimal function the following configuration is most satisfactory:

- The fresh gas inlet must be placed between the absorber and the inspiratory valve.
- The APL valve should be situated between the expiratory valve and the absorber.
- The bag/ventilator switch should be in the expiratory limb so that during IPPV exhaled gas will be vented through the APL valve.
- For optimal function the unidirectional valves should be close to the patient to prevent backflow into the inspiratory limb in the event of a leak in the circuit. They are however not placed in the Y-piece as in this position they would often be difficult to observe during surgery.

Valve malfunction can occur due to water condensation on the expiratory valve resulting in partial obstruction to expiration and rebreathing. Valve malfunction can also occur due to wearing of the valve seat.

Advantages include cost savings when using low gas flows, humidification and warming of gases, the ability to easily switch between spontaneous and controlled ventilation, decreased theatre pollution, and a reduction in the risk of fires and explosions when using inflammable agents such as cyclopropane and ether.

Disadvantages include the complexity of the system with multiple components, which can lead to misconnections, disconnections, and leaks. Valves stuck in the open position can cause rebreathing, and sticking of the expiratory valve can result in breath stacking and tension pneumothorax. The increased resistance to breathing will lead to increased work of breathing especially in paediatrics.

Resistance can be reduced by using circulation fans. Cross infection between patients is another potential problem that can be diminished by using appropriate filters, or abolished by using disposable circuits.

**Soda-lime**

In these systems, the expired carbon dioxide is removed by absorbing exhaled gas using an absorbing compound (either Soda-lime or Amsorb) contained in a canister. The remaining expired gas is then free to be inspired again without accumulation of carbon dioxide occurring.

Soda-lime is a mixture of 94% calcium hydroxide, 5% sodium hydroxide and 1% potassium hydroxide, silicates for binding (<1%) a pH sensitive indicator dye, and a water content of 14 – 19%. The calcium hydroxide provides the main capacity for carbon dioxide removal by soda lime, the potassium and sodium hydroxide being added to accelerate the rate of absorption. Amsorb contains no potassium hydroxide. The sodium hydroxide and water required are regenerated. Carbon dioxide absorption occurs by the following chemical reactions:

\[
\begin{align*}
H_2O + CO_2 & \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \\
NaOH (or KOH) + H_2CO_3 & \rightleftharpoons NaHCO_3 (or KHCO_3) + H_2O (+ heat) \ [fast \ reaction] \\
2NaHCO_3 (or KHCO_3) + Ca(OH)_2 & \rightleftharpoons 2NaOH (or KOH) + CaCO_3 + H_2O \ [slow \ reaction]
\end{align*}
\]

Amsorb contains calcium hydroxide and calcium chloride with substances to increase hardness.

Baralyme 20% barium hydroxide is no longer used because of its propensity to produce CO with desflurane, sevoflurane and isoflurane.

Soda-lime granules are usually between 4-8 mesh in size (will fit between a mesh of 4 – 8 strands / inch²). If granules are too small resistance to breathing increases and ‘dust’ may be inhaled.
granules are too large channelling will occur with inefficiency of CO$_2$ absorption. The volume of the space between granules should equal the volume of the granules. Double canisters are often used with a baffle to direct gas flow centrally to reduce channelling. Absorbers have a trap at the base to collect water and dust.

**Problems with chemicals used in absorbers to remove CO$_2$**

- Production of carbon monoxide. This particularly likely when absorbents are allowed to become desiccated, as may happen when gases are not switched off after use. Dangerous levels of carboxyhaemoglobin of up to 30% have been recorded. Baralyme was worse than other agents and was withdrawn from use in the US in 2004.
- Absorbents have been shown to absorb volatile agents and release them later leading to slower than expected induction, and emergence from anaesthesia.
- Compound A is a by-product of absorption of sevoflurane by absorbents. Although Compound A is nephrotoxic in some animals this is thought not to be a problem in humans.
- Historically, trichloroethylene (trilene) was shown to cause significant neurotoxicity in humans when used with soda lime.

There are two indicators in common usage - ethyl violet which turns from white to purple and the other changing from pink to white upon exhaustion, which may result in confusion.

**Advantages of rebreathing systems**

- Economy of anaesthetic consumption.
- Warming and humidification of the inspired gases.
- Reduced atmospheric pollution.

**Ideal properties of a breathing system/circuit**

- Ability to deliver a targeted anaesthetic concentration
- Suitable for spontaneous and assisted ventilation
- Minimise gas flow
- Remove carbon dioxide
- Low resistance
- Efficient (save volatile agent)
- Humidify and warm gases
- Easy to use and lightweight
- Allow scavenging of anaesthetic gases

**References**