



Vaporisers for anaesthesia

Outline



- Definition, development
- Physical basics
- Construction
- Modifications
- Safety
- Future

Anaesthesia vaporizer



- **Safety** of patient first.
- The anesthesia vaporizer is a **critical component** of anesthetic machine.
- It is very important to ensure that the appropriate **percentage** of anesthetic agent is being delivered.
- A **malfunctioning** vaporizer can be the cause of inappropriate depth of anesthesia and may also be the reason you “lose” a patient.
- Output +/- 15%

Definition



- A vaporizer is a device that transforms liquid anaesthetic to vapour and adds its clinically useful and precise, adjustable concentrations to a stream of carrier gas
- Saturated vapour pressure (SVP) of volatile anaesthetic agents at room temp is many times higher than required to produce anaesthesia

Raimundus Lullus, 1275

Paracelsus, "sweet oil of vitriol,, 16.
century

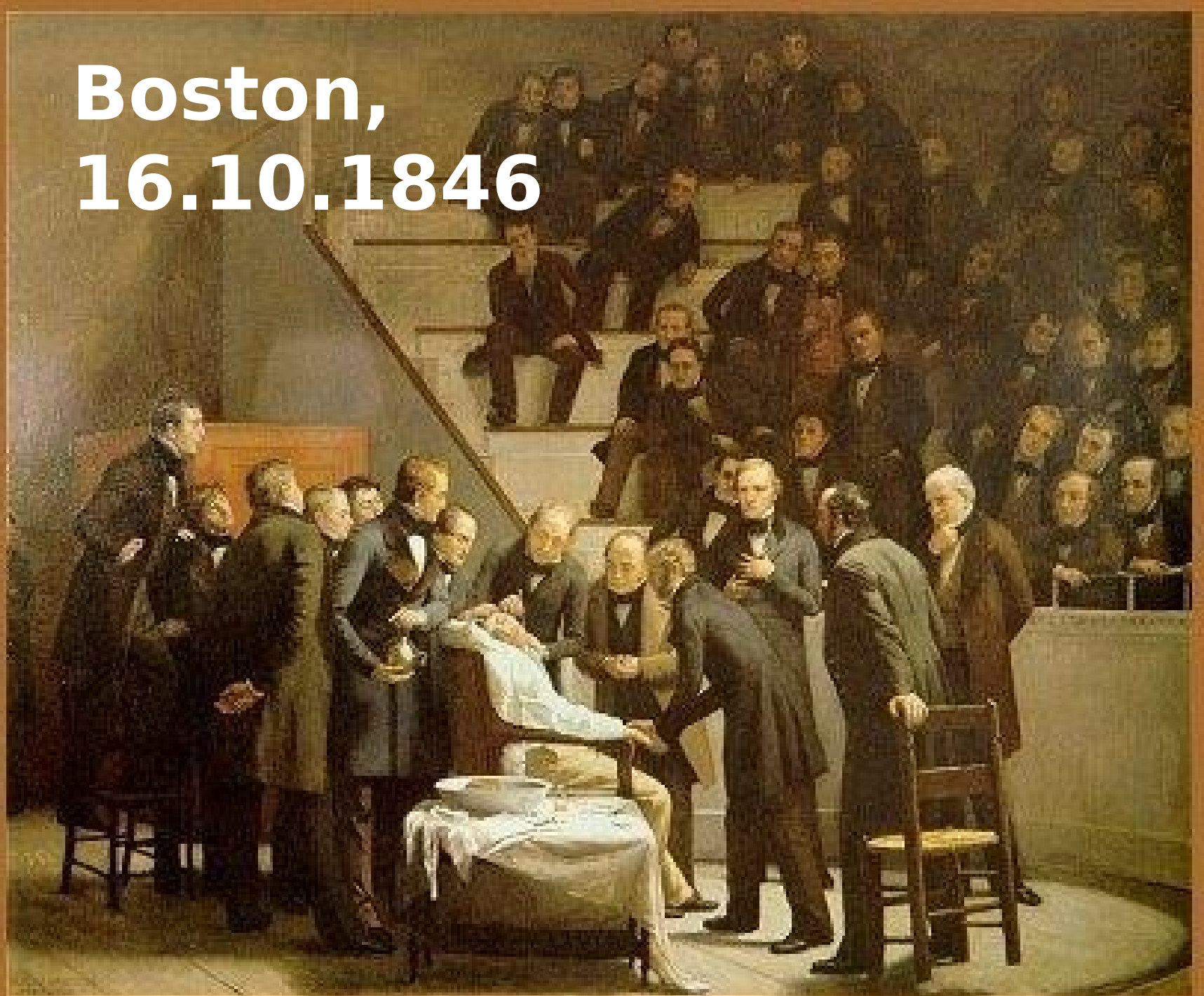
ONSITQVI SVI ESSE POTEST

...ar wunderbarlichen Sulphur geben / in dem/
so die Corpora Animantata geschieden werden von den Cor-
poribus Embryonatis. Als vom Saltz / vom Salgemmen/
von den Speciebus Aluminis, von den Vitriolis, &c. Nuhn
aber ein kurze Regel willich euch inn gemein geben / das alle
Sulphura von den Vitriolatis Salibus, Stupefactiua seindt/
Narcotica, Anodyna, Somnifera: Vnnd aber mit einer sol-
chen Proprietet / das an dem orth die Somniferisch arth / so
rühig vnnd so mildt hinget / das ohn allen schaden sich ab-
zeuget / nichts auff Opiatische Wirkung / als in Iulquiramo,
Papauere, Mandragora, &c. sondern gar Wildt / Zugends-
lich / ohn all Insectiff. Darumb ich das zum höchsten leb / das
ein solch Somniferum Stupefactiuum soll von der Natur
selbst Decoquiert sein / Prepariert vnnd Corrigiert. Vnnd
diereil wir Arst alle sehend / das die Somnifera viel thundt/
vnnd grosse ding thundt / vnnd das aber in den Opiaten ein
solchs Gift ist / das sie nicht zu gebrauchen seindt ohn die ge-
stalt Quintae Essentiae: So sollen wir vnser Zuflucht vnd Ver-
standt deßer mehr seuen hie an das orth / diereil wir wissen/
das viel krankheiten seindt / die ohn Anodyna nicht mögendt
geheylt werden vnnd all ihr Cur in die Anodynyn gefest sendt
von Gott durch die Natur. Darumb beweget mich dasselbig/
diesen Sulphur deßer das zu beschreiben: Wie er gefundt wird/
vnnd wie man ihn zu wegen bringet / werdt ihr finden inn den
Alchimistischen Processen. Hie sollendt ihr aber wissen von



diesem Sulphur / das vnter allen der vom Vitriol am bekannt-
lichsten ist / das er an ihm selbst Sux ist: Zum andern hatt er ein
Suessse / das ihn die Hünner all essen / vnd aber endtschlaffen
auff ein Zeit / ohn schaden wieder auffstohndt. Diesen Sulz

**Boston,
16.10.1846**

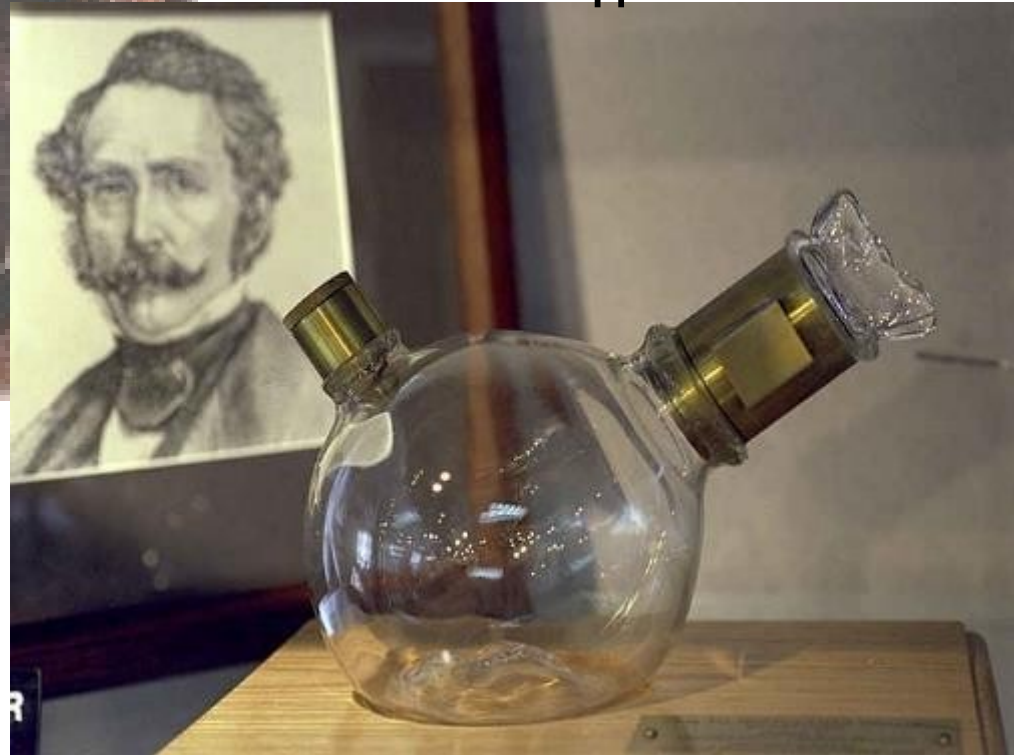


**Boston,
16.X.1846**



W.T.G. Morton
n

Ether
Draw-
over No
control



REMARKS

ON THE

PROPER MODE OF ADMINISTERING

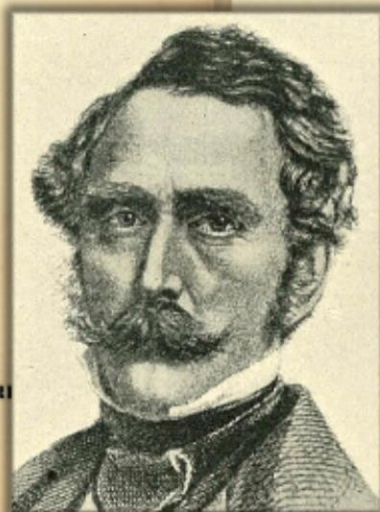
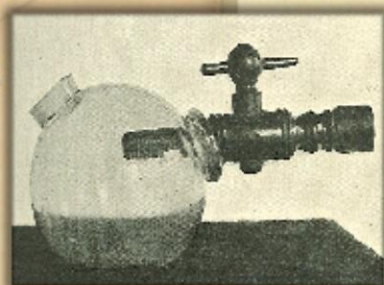
SULPHURIC ETHER

BY INHALATION.

BOSTON:

DUTTON AND WENTWORTH, PRS

1847.



TO THE

SURGEONS OF THE MASS. GEN. HOSPITAL,

THIS LITTLE WORK IS RESPECTFULLY DEDICATED,

AS AN EVIDENCE

THAT THEIR EARLY AND CONTINUED INTEREST IN THE ADMINISTRATION OF SULPHURIC ETHER

IS GRATEFULLY APPRECIATED,

BY THEIR

OBT. SERV'T.

WM. T. G. MORTON.

J. Y. Simpson
ANÆSTHESIA,

OR THE

EMPLOYMENT OF

CHLOROFORM AND ETHER

IN

SURGERY, MIDWIFERY, ETC.

BY

J. Y. SIMPSON, M.D., F.R.S.E.,

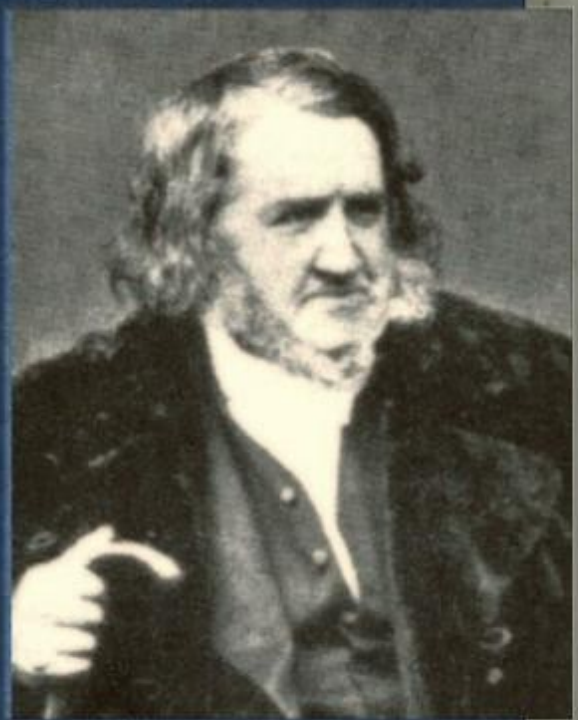
PROFESSOR OF MIDWIFERY IN THE UNIVERSITY OF EDINBURGH, PHYSICIAN-
ACCOUCHER TO THE QUEEN IN SCOTLAND, ETC. ETC. ETC.



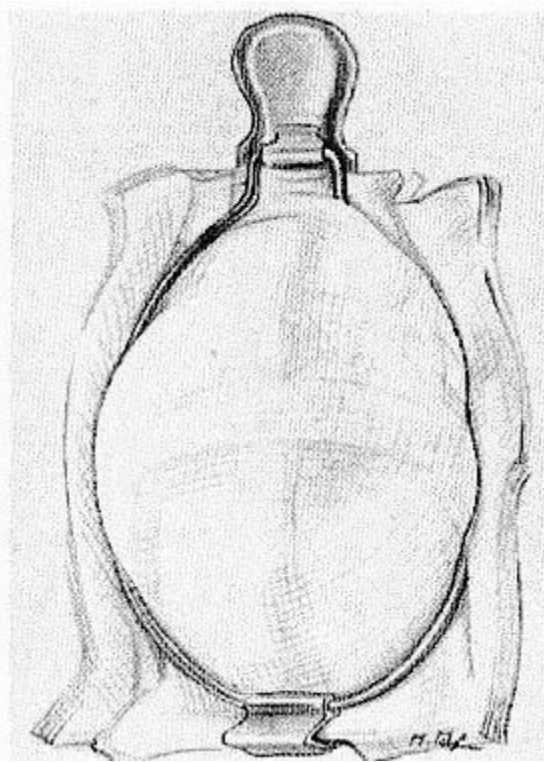
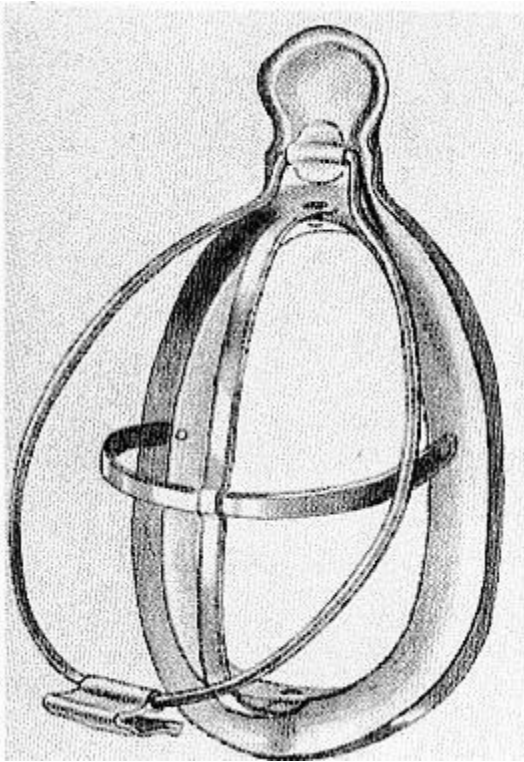
PHILADELPHIA:

LINDSAY & BLAKISTON.

1849.



Carl Schimelbusch, 1890



Ether,
chlorform
Draw over
Some control

Generic simple flow in vapouriser

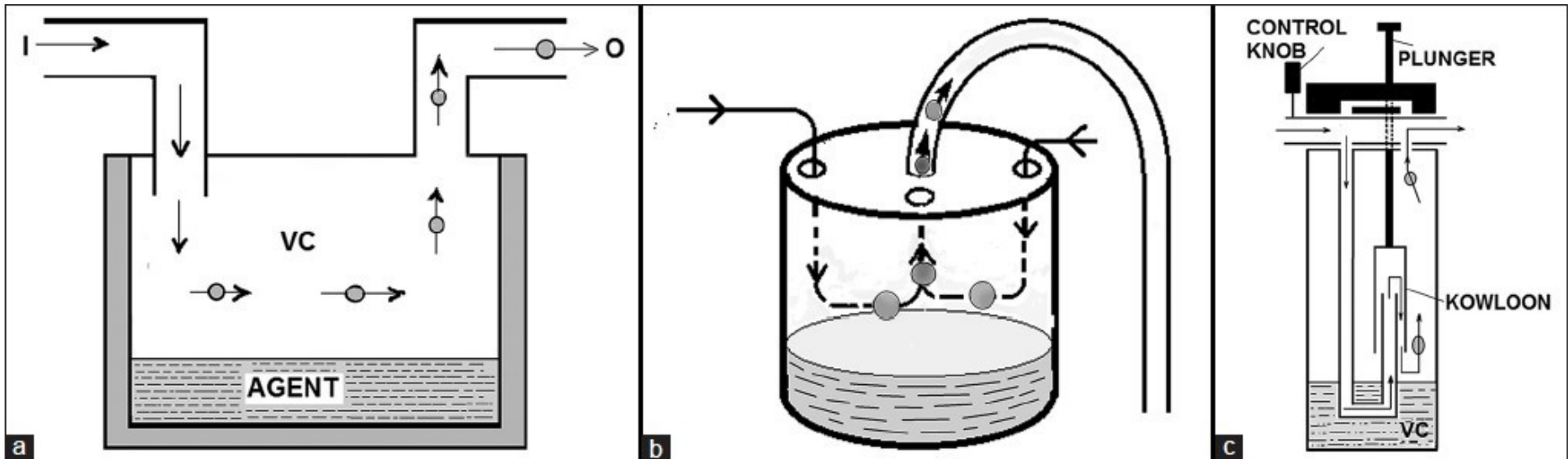


Figure 1: (a) Generic simple flow over vapouriser: I – Inlet port; O – Outlet port; vapourising chamber; Plain arrow shows fresh gas flow (FGF); Arrow with circle shows FGF carrying vapour; (b) Flagg can; (c) Boyle's bottle

A bit of physics



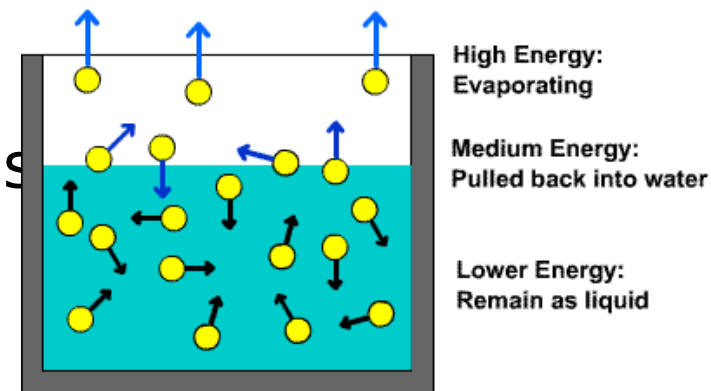
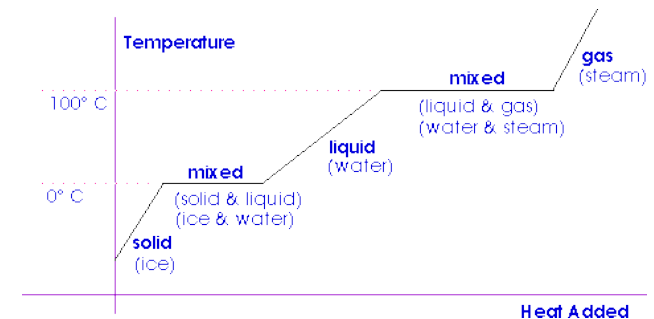
1. Gas / vapour
2. Critical temperature
3. Latent heat of evaporation
4. Boiling point
5. Saturated water pressure (SVP)
6. Partial pressure (Dalton law)

Physics of vaporisers

- **Vapor pressure:** Molecules escape from a volatile liquid to the vapor phase, creating a "saturated vapor pressure" at equilibrium. **Vapor pressure (VP) increases with temperature.** VP is independent of atmospheric pressure, it depends only on the physical characteristics of the liquid, and its temperature.
- **Latent heat of vaporization** is the number of calories needed to convert 1 g of liquid to vapor, without temperature change in the remaining liquid. The temperature of the remaining liquid will drop as vaporization proceeds, lowering VP, unless this is prevented.
- **Specific heat** is the number of calories needed to increase the temperature of 1 g of a substance by 1 degree C. Vaporizer – materials with high specific heats to minimize temperature changes associated with vaporization.
- **Thermal conductivity** - a measure of how fast a substance transmits heat. High thermal conductivity is desirable in

1. Gas / vapour

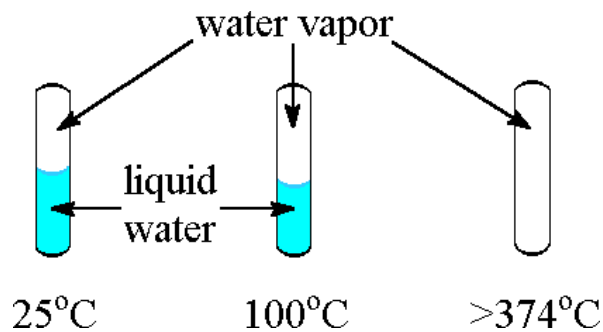
- Evaporation: in liquid some molecules have enough energy to leave the liquid
= evaporation
- Only on surface, requires heat energy
- Corelated with
 - a) temperature
 - b) surface
 - c) removal of vapour molecules
- Boiling point: $P_{\text{vapour}} = P_{\text{atm}}$



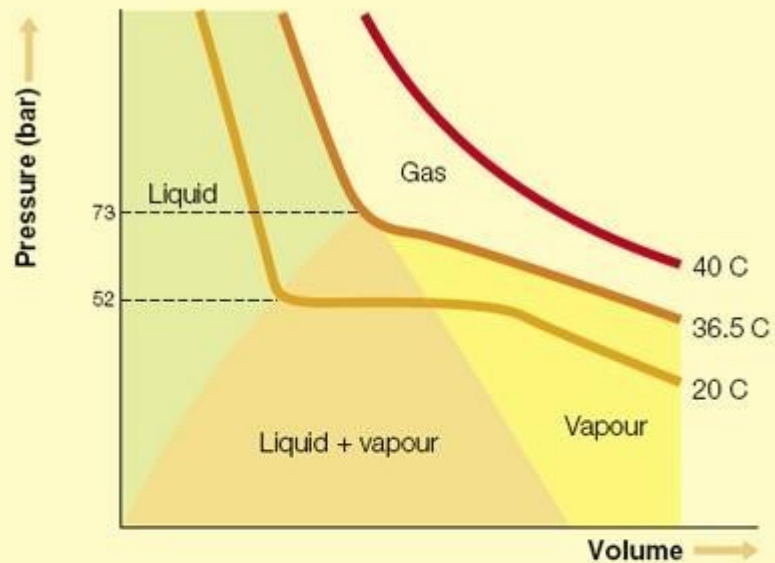
Critical temperature (CT)

- Temperature, above which a substance cannot be liquified, irrespective of pressure.
Now it is **GAS**.
- Below CT the substance can exist as **liquid or vapour**.
- **Gas**: substance above CT; no liquid possible
- **Vapour**: below CT, can be pressed to liquid

2. Critical temperature

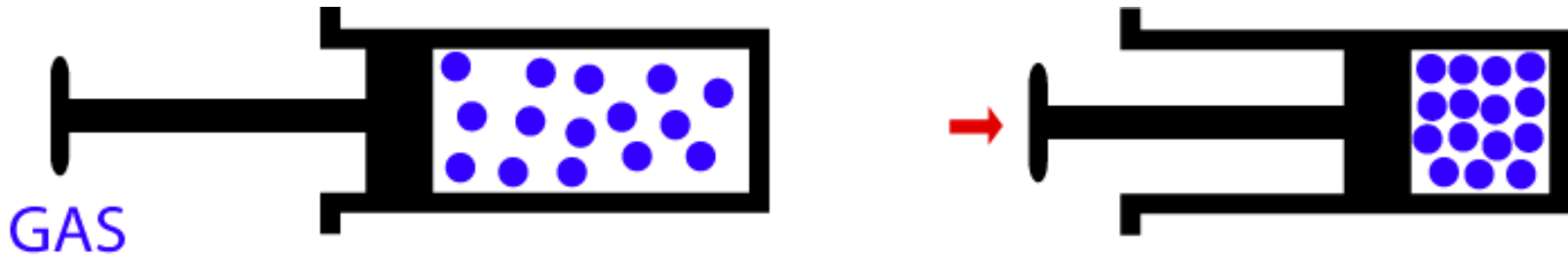


Isotherms of nitrous oxide

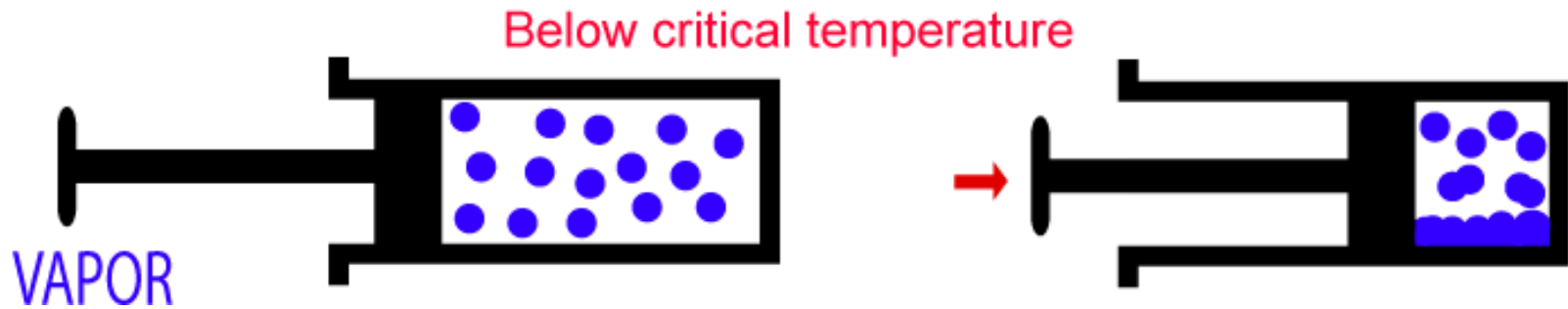


The isotherm at 40°C is above the critical temperature of nitrous oxide (36.5°C) and therefore obeys Boyle's law. As the volume decreases the pressure rises. At the critical temperature 36.5°C there is a critical pressure at which nitrous oxide becomes a liquid. Liquids are relatively incompressible and therefore a decrease in volume leads to a dramatic rise in pressure. At 20°C as the nitrous oxide is compressed some of it liquefies at a pressure of 52 bar (saturated vapour pressure of nitrous oxide). Further reduction in volume causes more vapour to condense with no change in pressure. When all the vapour is condensed to liquid a rapid rise in pressure is seen with further decrease in volume.

Critical temperature



Above critical temperature



Below critical temperature

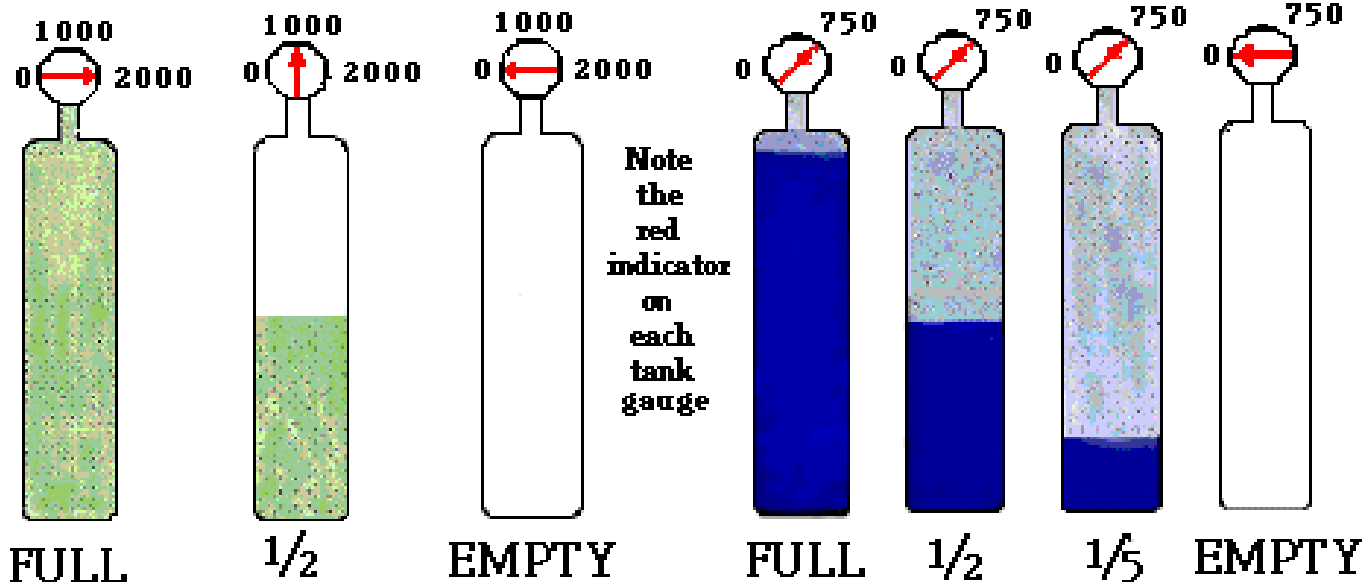
Oxygen and nitrous oxide

Oxygen: T_c -119°C

N_2O : T_c 36.5°C

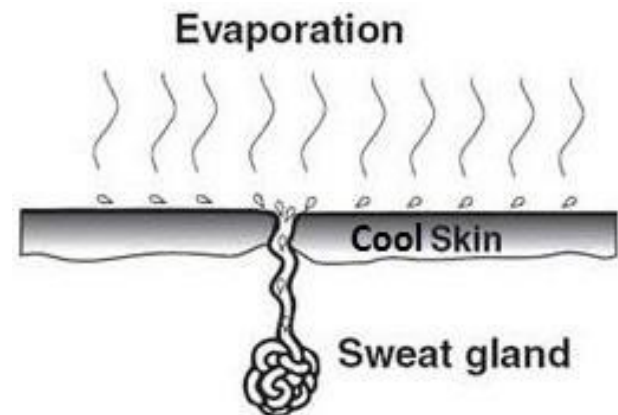
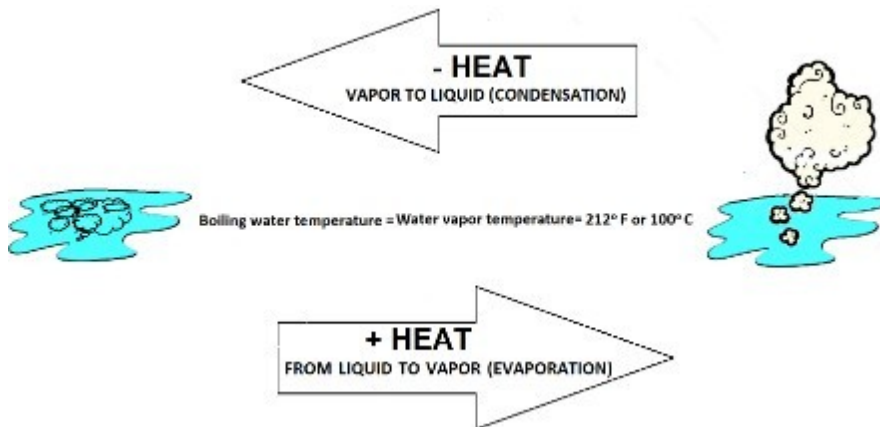
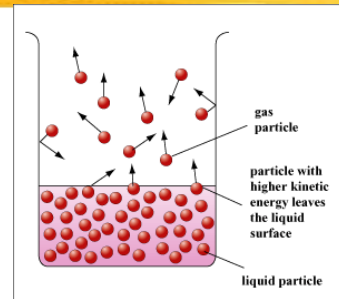
At 22°C and 15 MPa:
gas

At 22°C and 5 MPa: liquid +
gas



3. Latent heat of evaporation

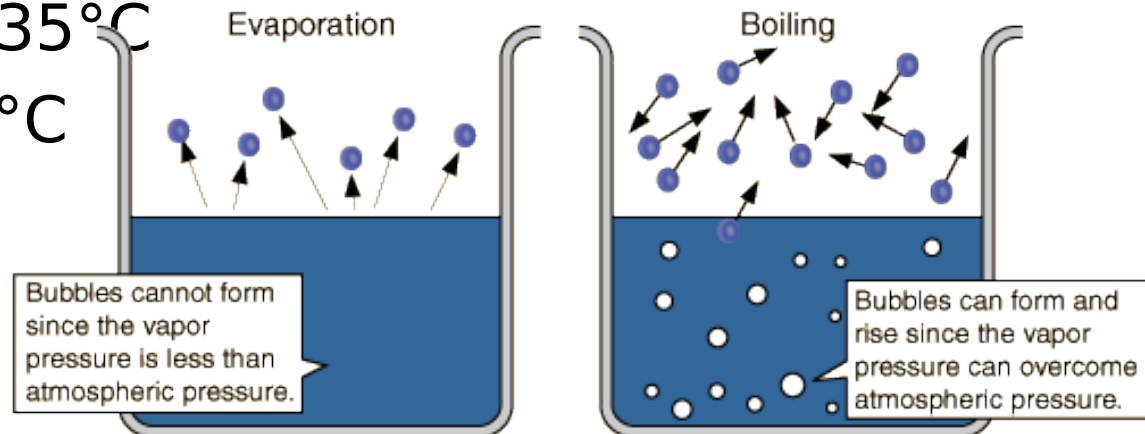
- Molecules leaving liquid
- Average energy falls, liquid cools
- Heat energy required to evaporate the liquid



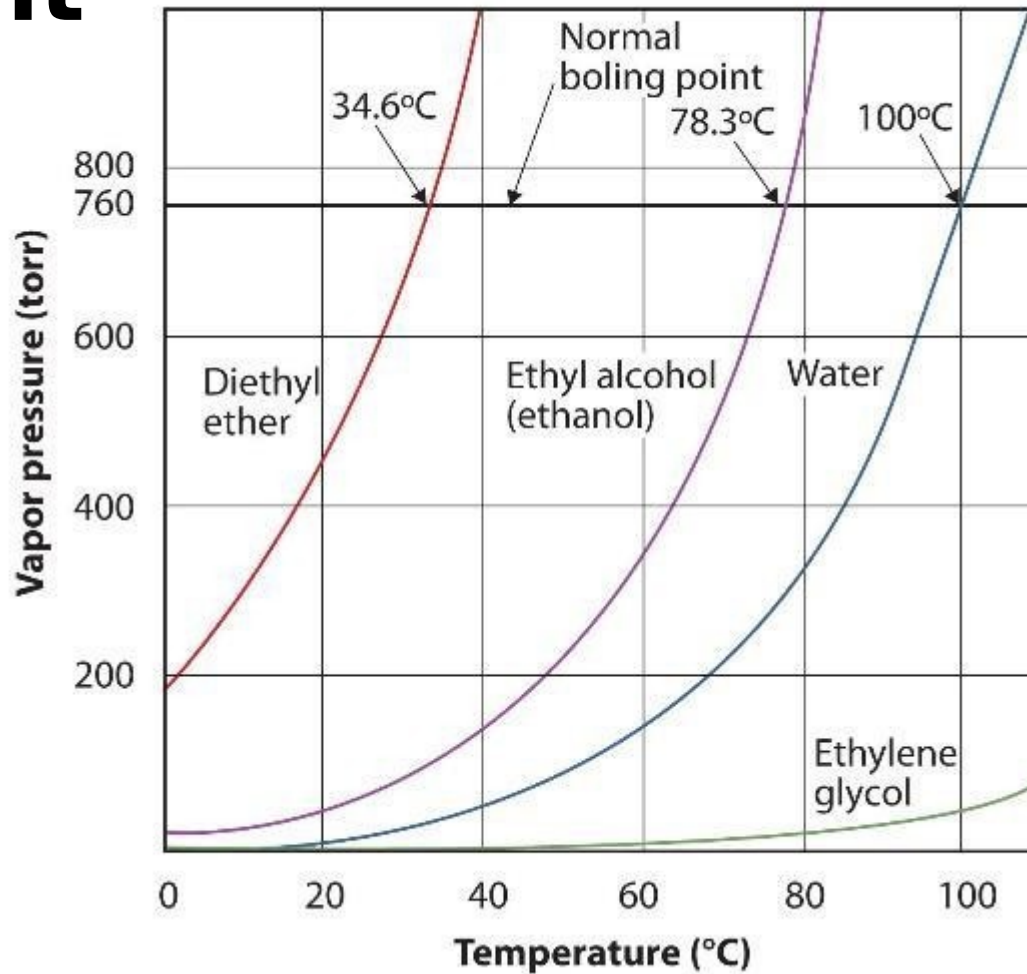
4. Boiling point

- Higher temperature $\approx$ quicker evaporation
- Boiling point: the pressure of vapour = atmospheric pressure
- **Inside** evaporation; bubbles of saturated vapour
- The closer the liquid to BP, the quicker turn to vapour

Ether BP: 35°C
Water BP: 100°C



Boiling point



5. Saturated water pressure (SVP)

- Evaporation in a **closed container** will proceed until there are as many molecules **returning** to the liquid as there are **escaping**.
- At this point the **vapour is saturated**; for given temperature independent of pressure!
- Pressure of that vapor is called the **saturated vapor pressure**.
- Boiling point: temperature at which $SVP = P_{atm}$

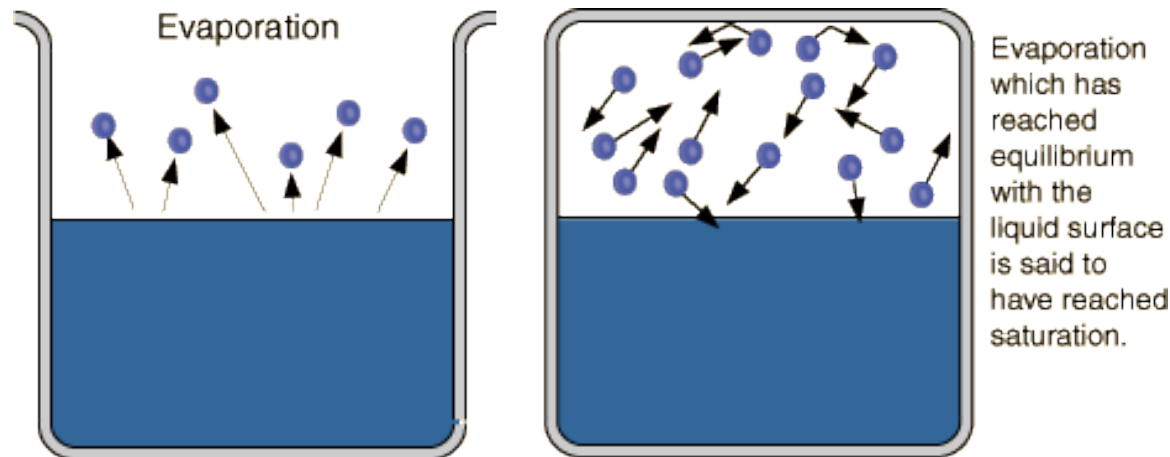
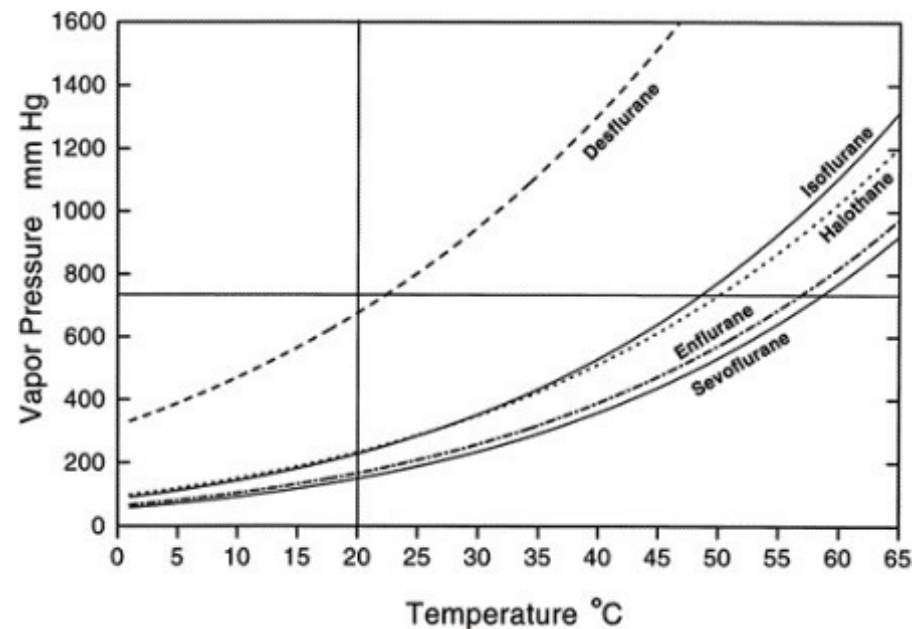
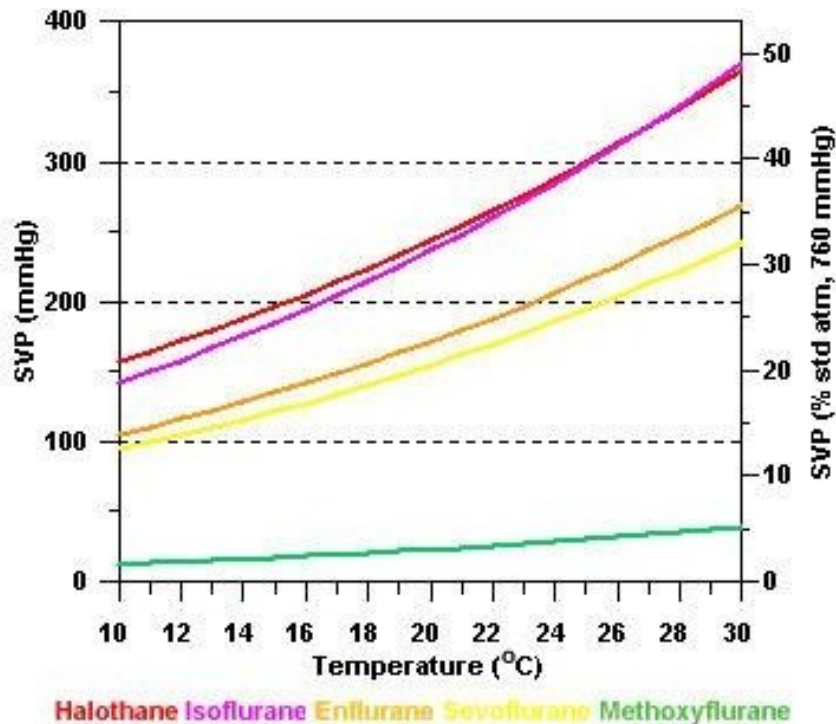


Table 1 - The saturated vapour pressures of some common volatile anaesthetics at 20°C

	SVP at 20°C (kPa)
Ether	59
Halothane	32
Enflurane	23
Desflurane	88.5
Isoflurane	33
Sevoflurane	21



SVP and anaesthesia

- To generate known concentration of inhalation agent (vapour)
- Dalton law (partial pressures)
$$P_1 + P_2 + P_3 \dots = P_{\text{total}}$$
- P_{part} is proportional to the **volume** occupied by vapour in the mixture
- Concentration of agent: saturated vapour of liquid $\approx$ volume% $\approx$ concentration
- E.g. Sevoflurane SVP at 20°C = 21 %



Concentration of anaesthetic vapour in gas

$$\text{Gas concentration} = \frac{\text{Vapour pressure}}{\text{Ambient pressure}}$$

$$\text{Sevoflurane conc.} = \frac{21.3}{101.3} = 21\%$$

This is too high
concentration

SVP and temperature

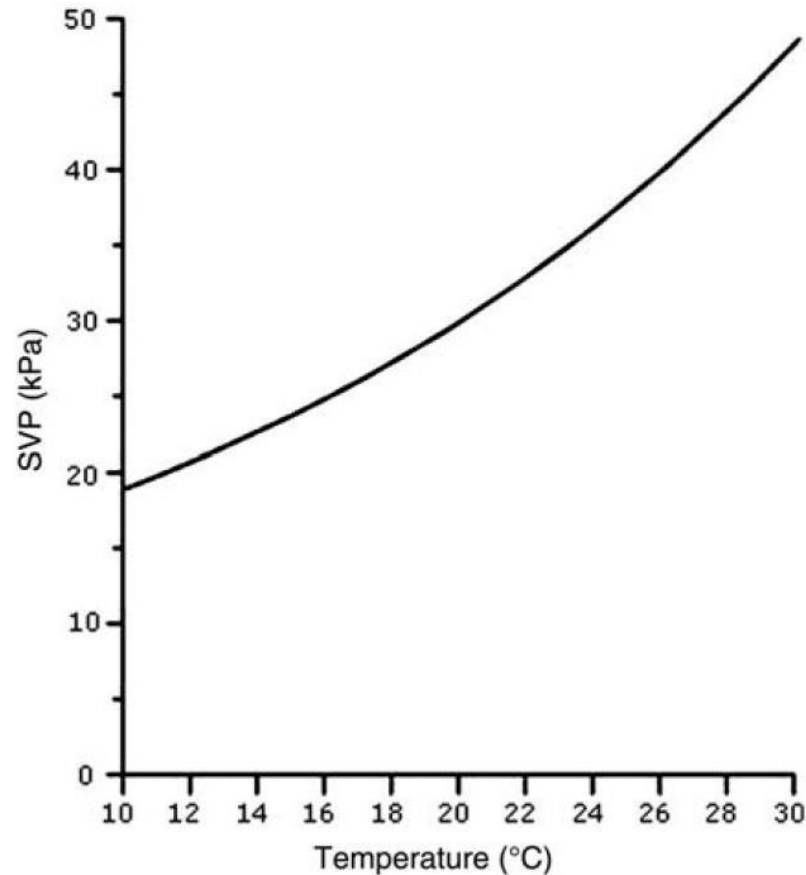
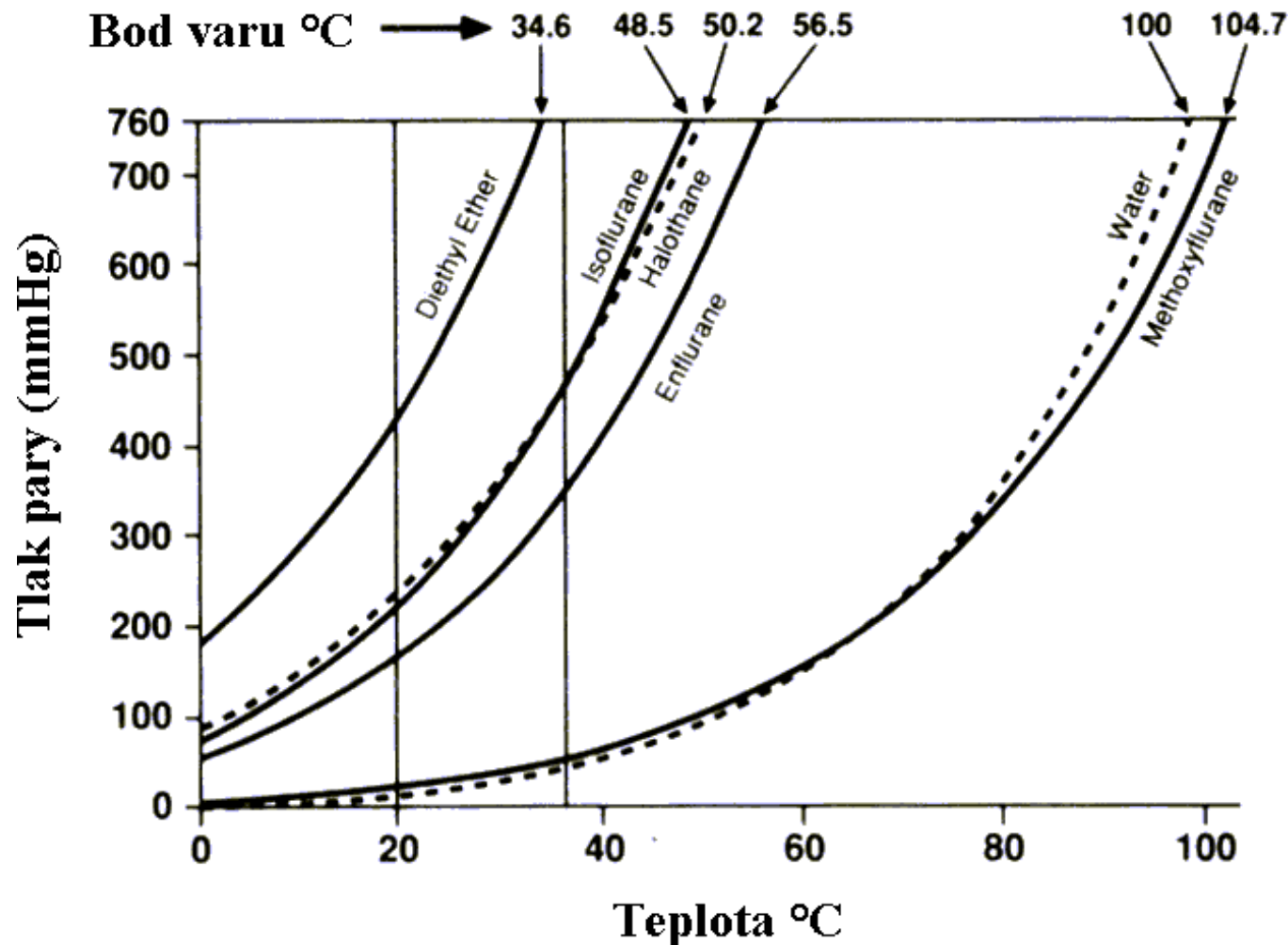


Fig 1 SVP increases non-linearly with temperature. Reproduced with permission of e-Learning Anaesthesia.

Relation between temperature and pressure of saturated vapour - volatility





Vaporisers - requirements

1. Simple, safety, user friendly
2. Precise, accurate concentration of anaesth. vapour
3. Ambient and evaporation temperature stability
4. Pressure, flow stability
5. Carrier gas independent
6. Agent specificity
7. Safe against
 - wrong liquid
 - tilt, leak, corrosion
 - electronic failure
8. Simple service, maintenance

Vaporiser classification

- **A. Method of vaporisation**
 1. Flow over
 2. Bubble through
 3. Injection
- **B. Resistance**
 1. Low (draw over, inhalers)
 2. Plenum
- **C. Location**
 1. Outside the circuit
 2. Inside the circuit
- **D. Regulation of concentration**
 1. Variable bypass
 2. Measured flow
 3. Electronic
- **E. Temperature stability**
 1. None
 2. By supplied heat
 3. By flow alteration
 4. Thermocompensation
(mechanical, computerized)
- **F. Specificity**
 1. Agent specific
 2. Multiple agents

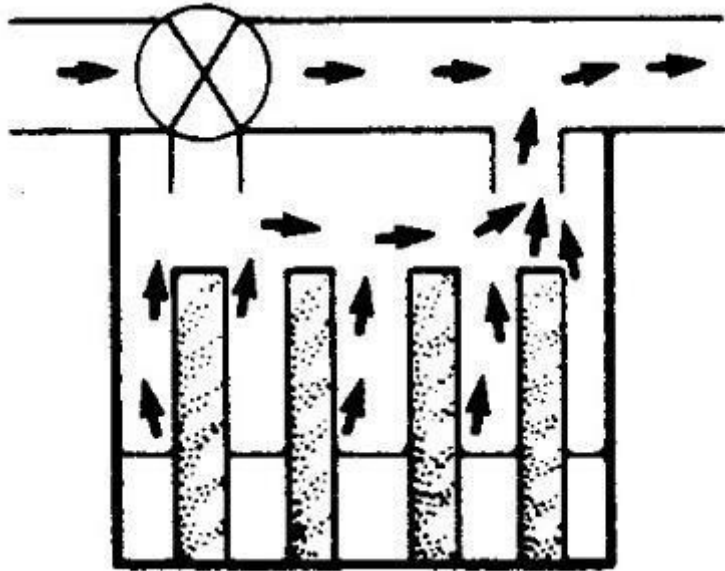
Vaporisers - development

- Ether / chloroform inhalers
- Wick vaporisers
- Draw/push over vaporiser
- Precise modern „plenum“ vaporisers
- Desfluran - challenge

A.

Evaporation

Goal: saturated vapour



Wick

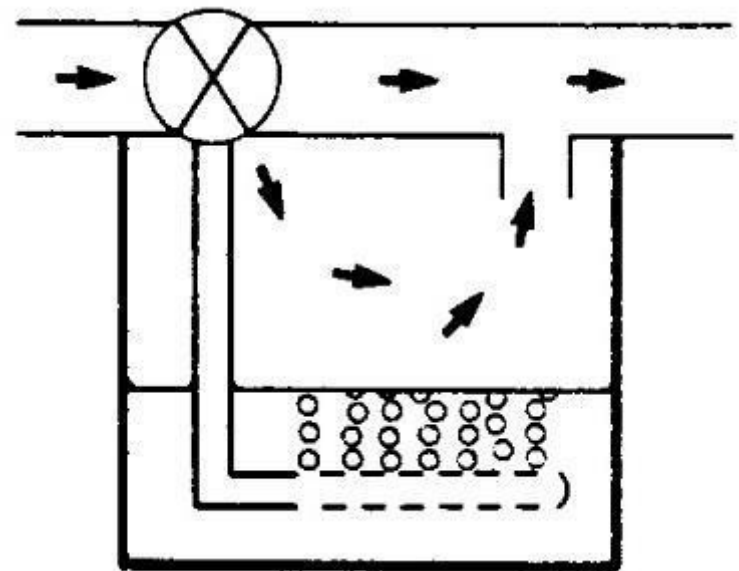


Plate with holes

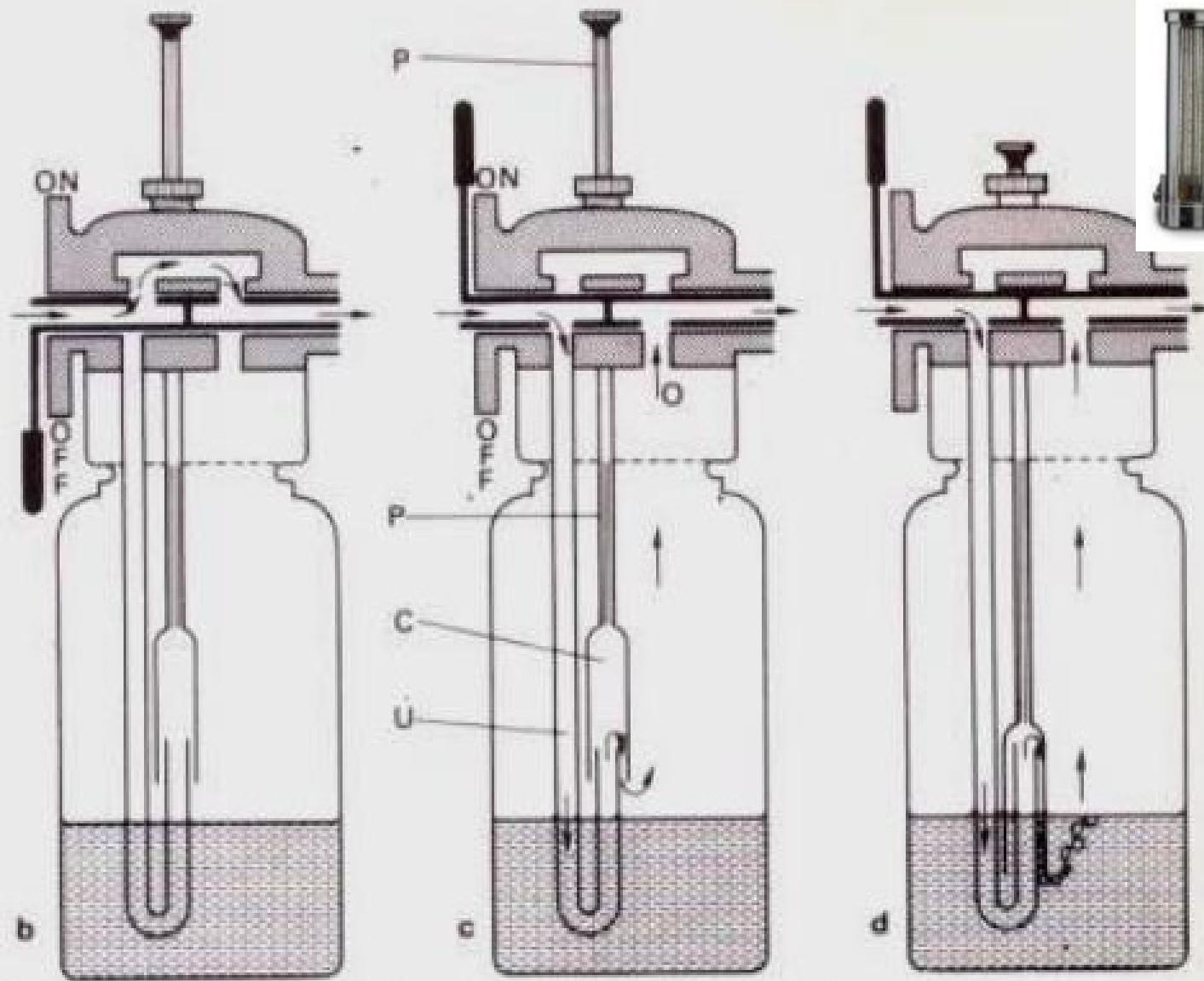


FIG. 69. (a) The Boyle's bottle. (b) Shows the control valve in the 'off' position, (c) shows the control lever fully on and the cowl (C) causing the gas to impinge on the surface of the liquid, and in (d) the cowl has been lowered so far that the gas bubbles through the liquid.

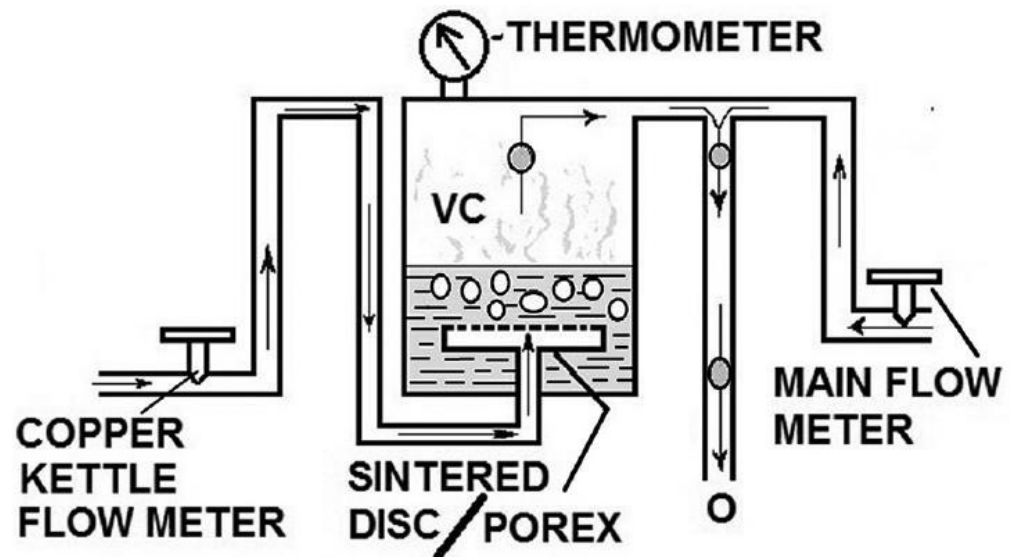
Cooper kettle

Bubble through

Agent not
specific Out of
circuit

Not temp.
comp.

Measured flow

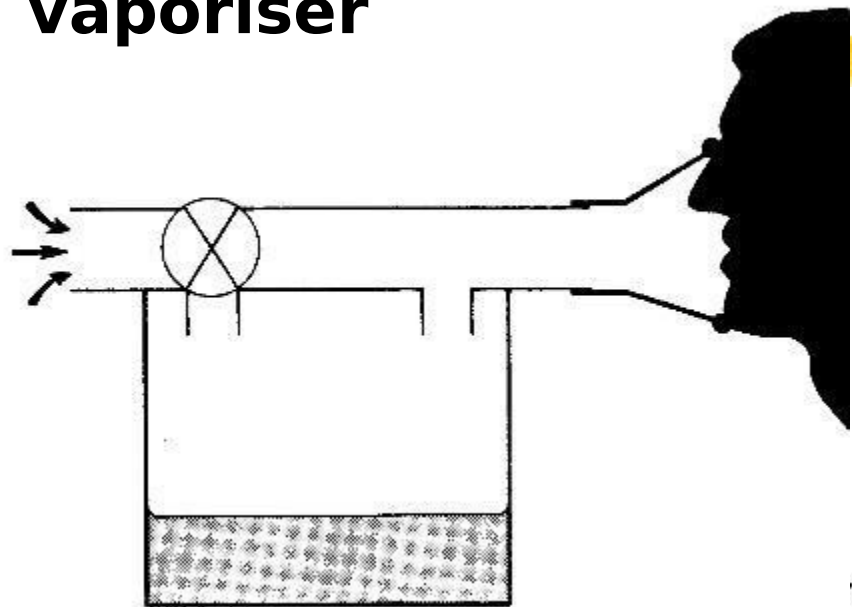


B.

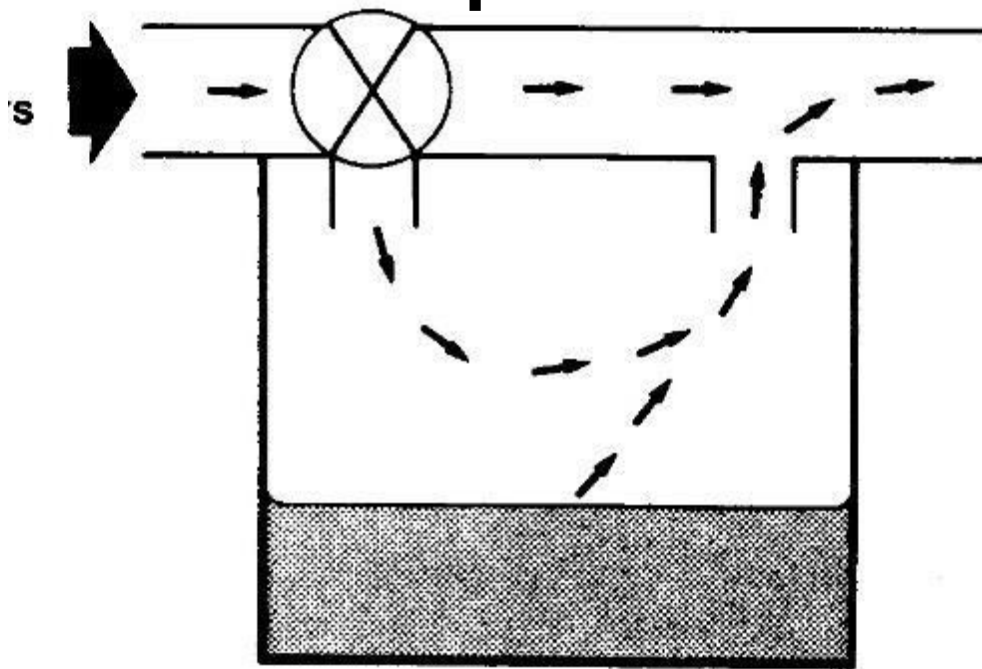
Resistance

- 1. **Draw-over** vaporizers - a sub atmospheric pressure is developed downstream of the vaporizer (e.g. patients respiratory efforts), drawing the gas through
- 2. **Plenum** vaporizers - positive pressure developed upstream (by a flowmeter) so that the gas is pushed through the vaporizer

**Draw over
vaporiser**

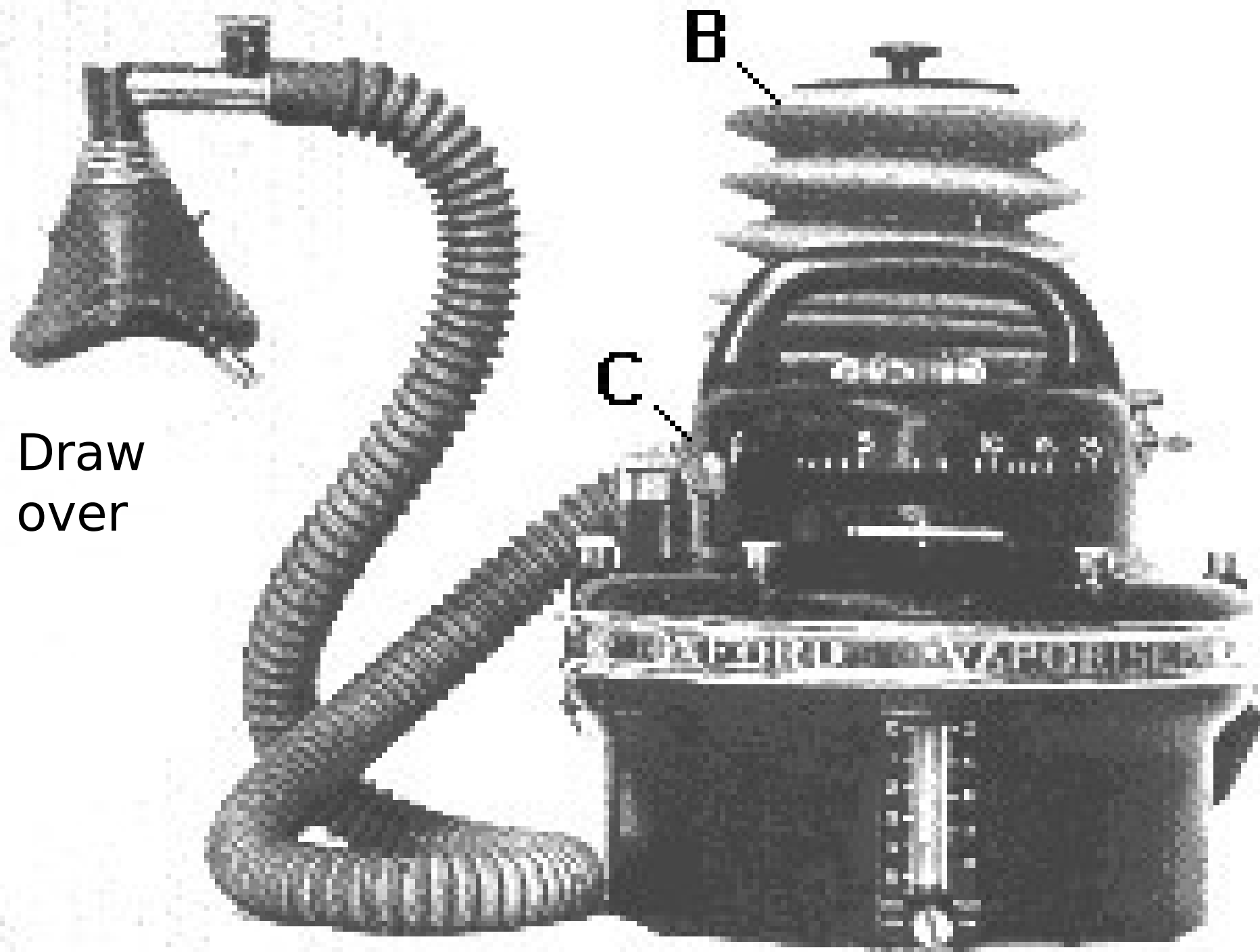


**Plenum
vaporizer**



Draw over vaporisers

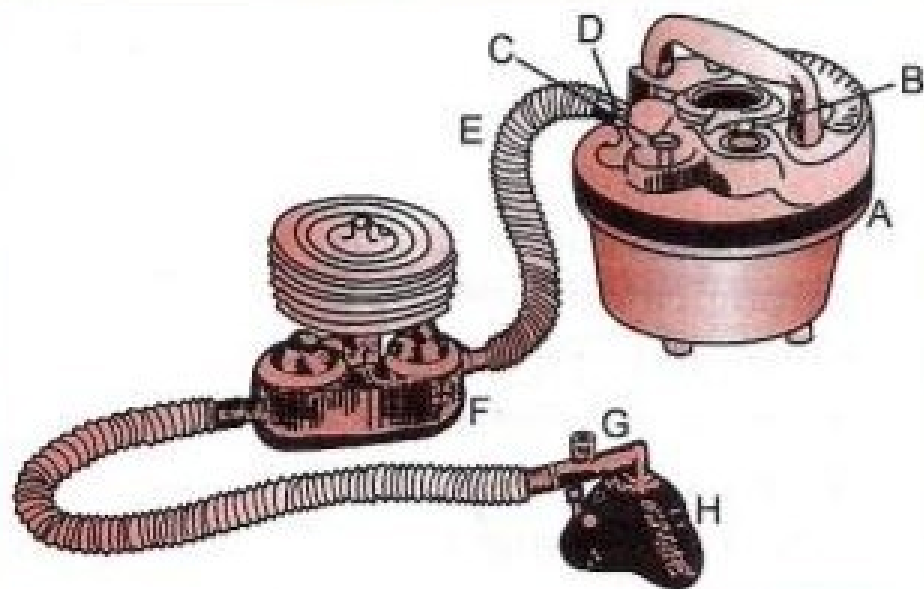
- Low resistance to flow
- Patient can „draw“ fresh gases over the volatile drug
- No pressurised gas needed
- Spontaneous / mechanical ventilation
- Distant places
 - EMO (Epstein, Macintosh, Oxford)
 - Oxford miniature vaporiser



Draw
over

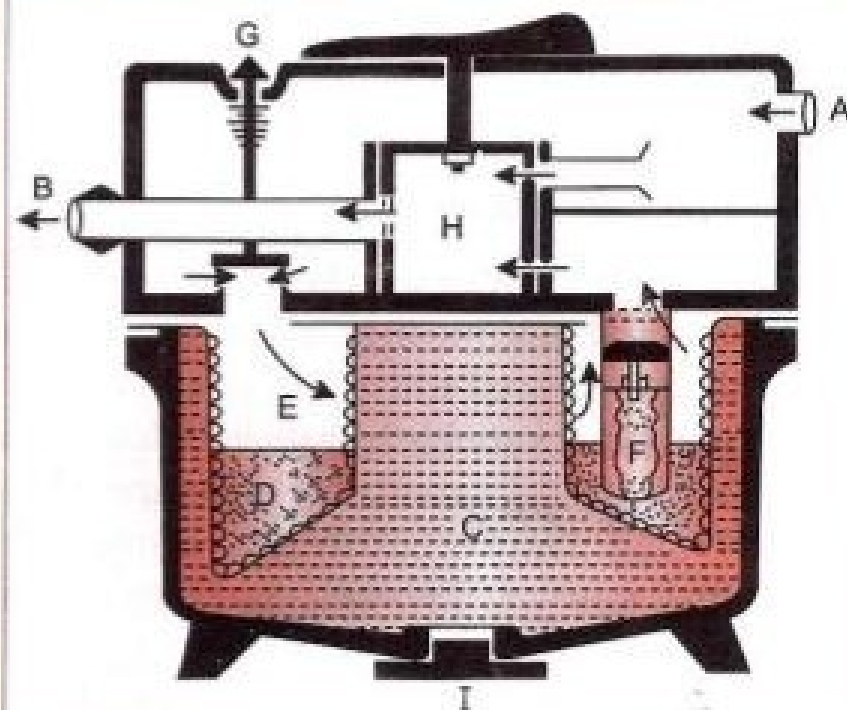
EMO / OMV vaporisers





EMO inhaler with Oxford inflating bellows

A = Inlet, B = Temperature compensator indicator, C = Ether filler, D = Ether level indicator, E = Hose from outlet, F = Oxford inflating bellows, G = Expiratory valve, H = Face mask

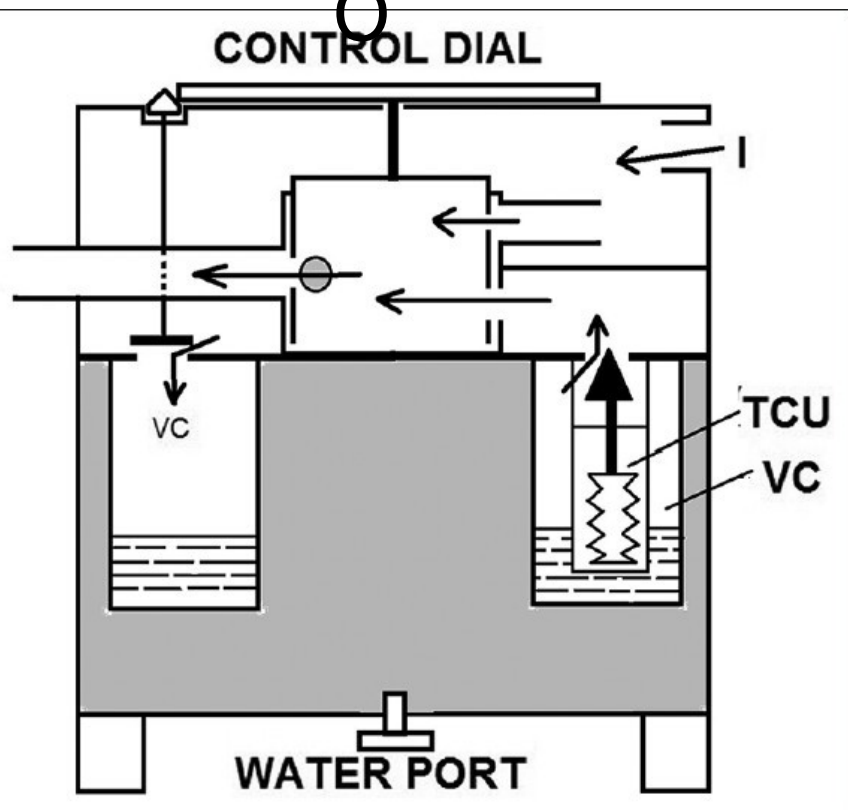


Schematic diagram of EMO inhaler
A = Inlet, B = Outlet, C = Water compartment, D = Ether, E = Vaporizing chamber, F = Thermo-compensating valve, G = Off/on valve, H = Mixing chamber, I = Water drain

Draw over vaporisers

EM

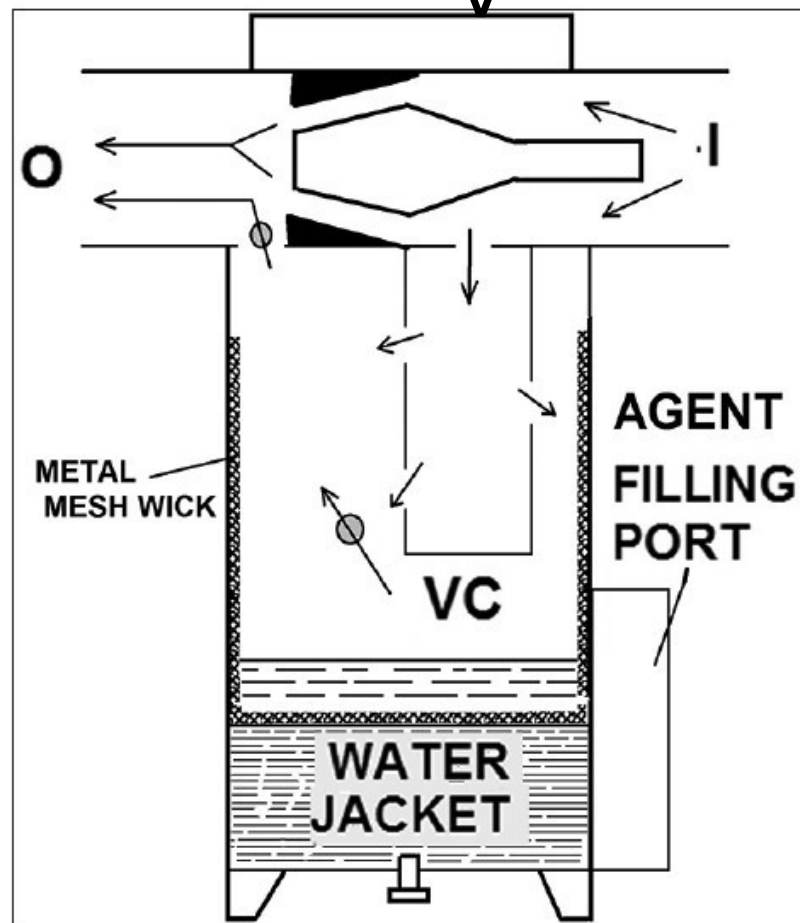
O



Epstein, Macintosh and Oxford

OM

V



: Oxford miniature vapouriser

Table 1 Drawover anaesthesia

Advantages

Simplicity of concept and assembly, with inherent safety
No need for pressurised gas supply, regulators and flow meters
Minimum FiO_2 is ~21%
Robust, reliable, easily serviced equipment

Low cost (purchase and maintenance)

Portable, suitable for field anaesthesia

Disadvantages

Decreasing familiarity with the technique and equipment
Vaporiser limitations
* Filling systems not agent specific (potential advantage)
* Basic temperature compensation, affecting performance at extremes

Less easy to observe spontaneous ventilation with self inflating bag

Cumbersome in paediatric use, unless lightweight tubing is available

Flow over (plenum) vaporisers

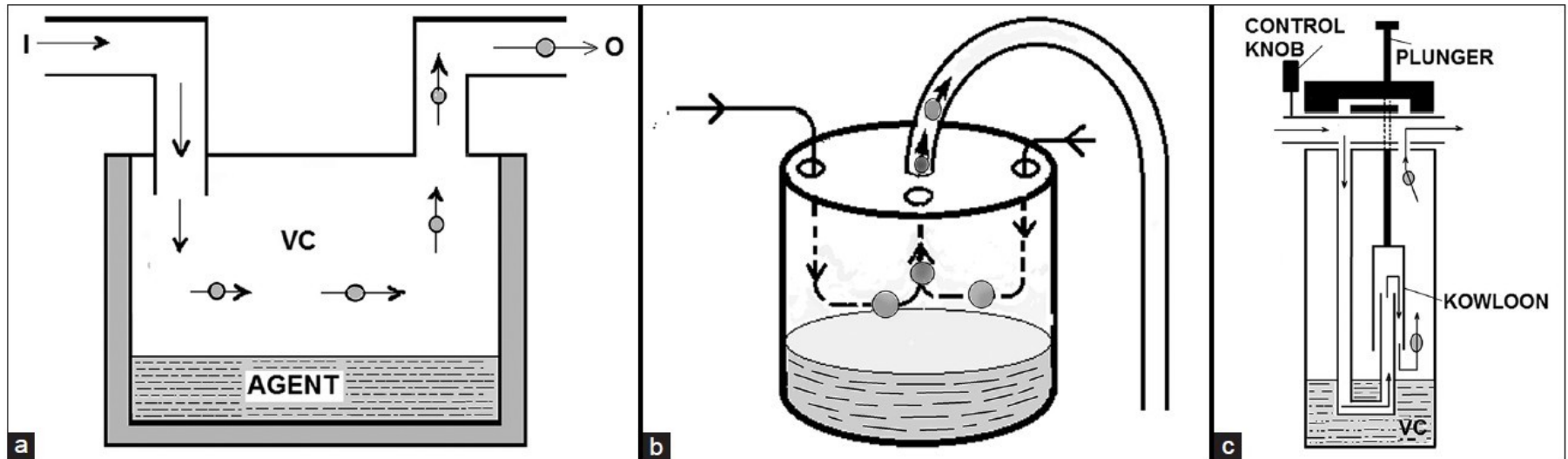


Figure 1: (a) Generic simple flow over vapouriser: I – Inlet port; O – Outlet port; vapourising chamber; Plain arrow shows fresh gas flow (FGF); Arrow with circle shows FGF carrying vapour; (b) Flagg can; (c) Boyle's bottle

Early vapourisers

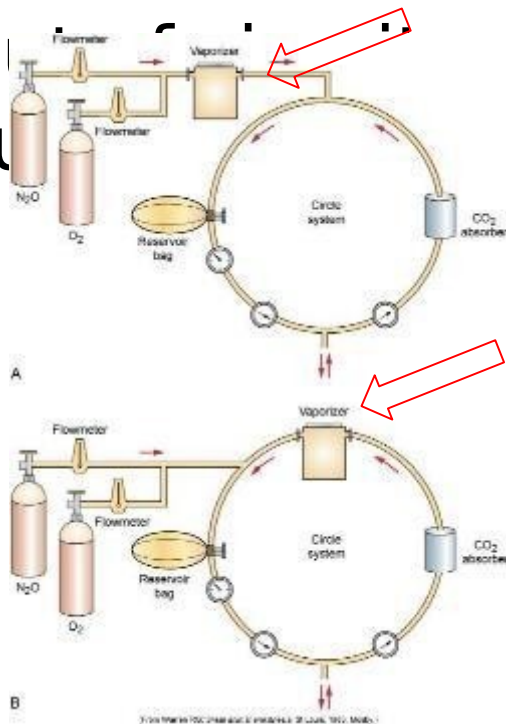
- Made general anaesthesia possible
- Problems with **effectiveness of evaporation**
(SVP, concentration)
- Problem with **cooling** during vapourisation (decrease of SVP)
- **Variation** with pressure and flow

C.

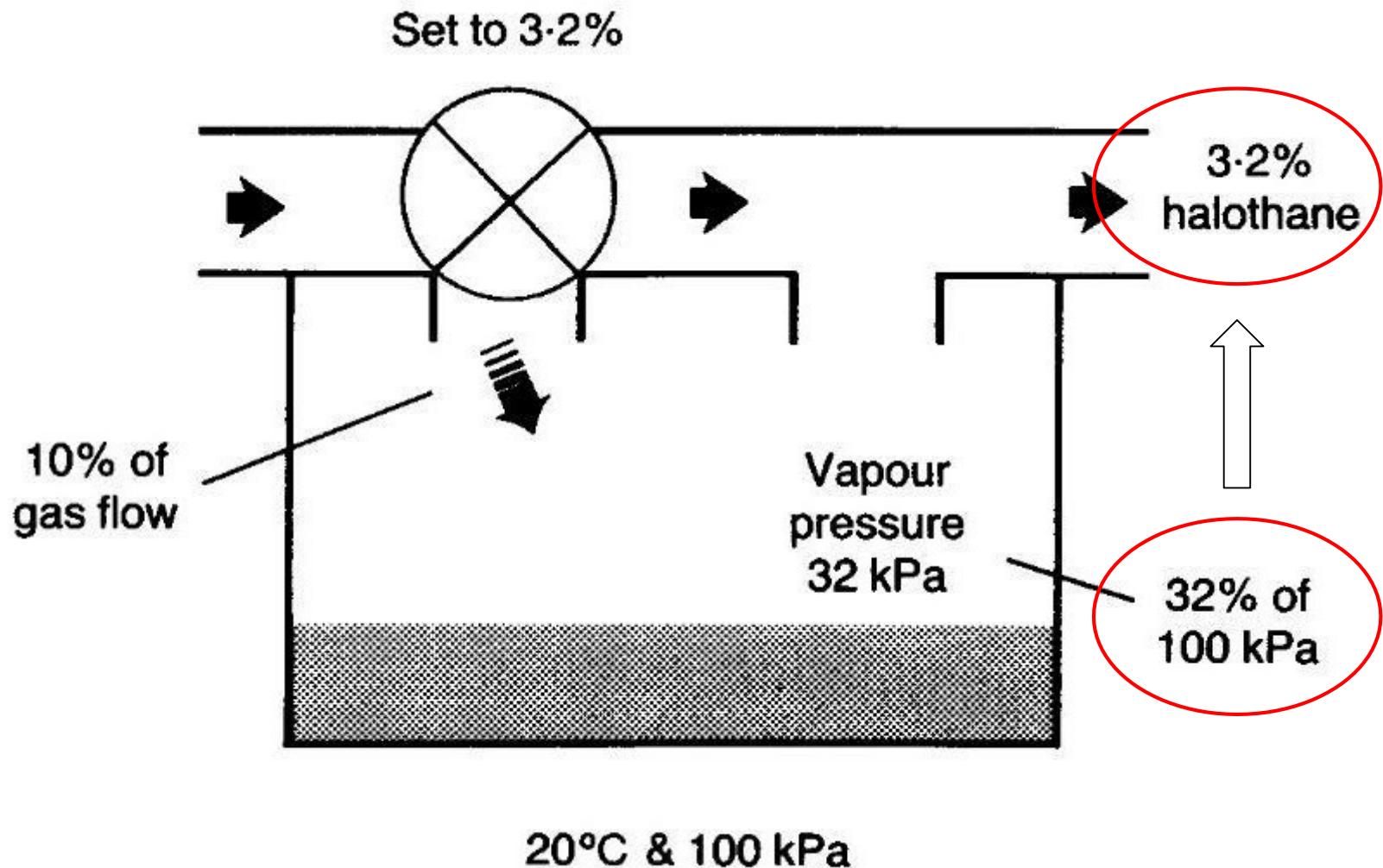
Location

1. In circuit – insp. or exp. arm, low resistance

2. Out of circuit – between rotameters and



D. Regulation of concentration



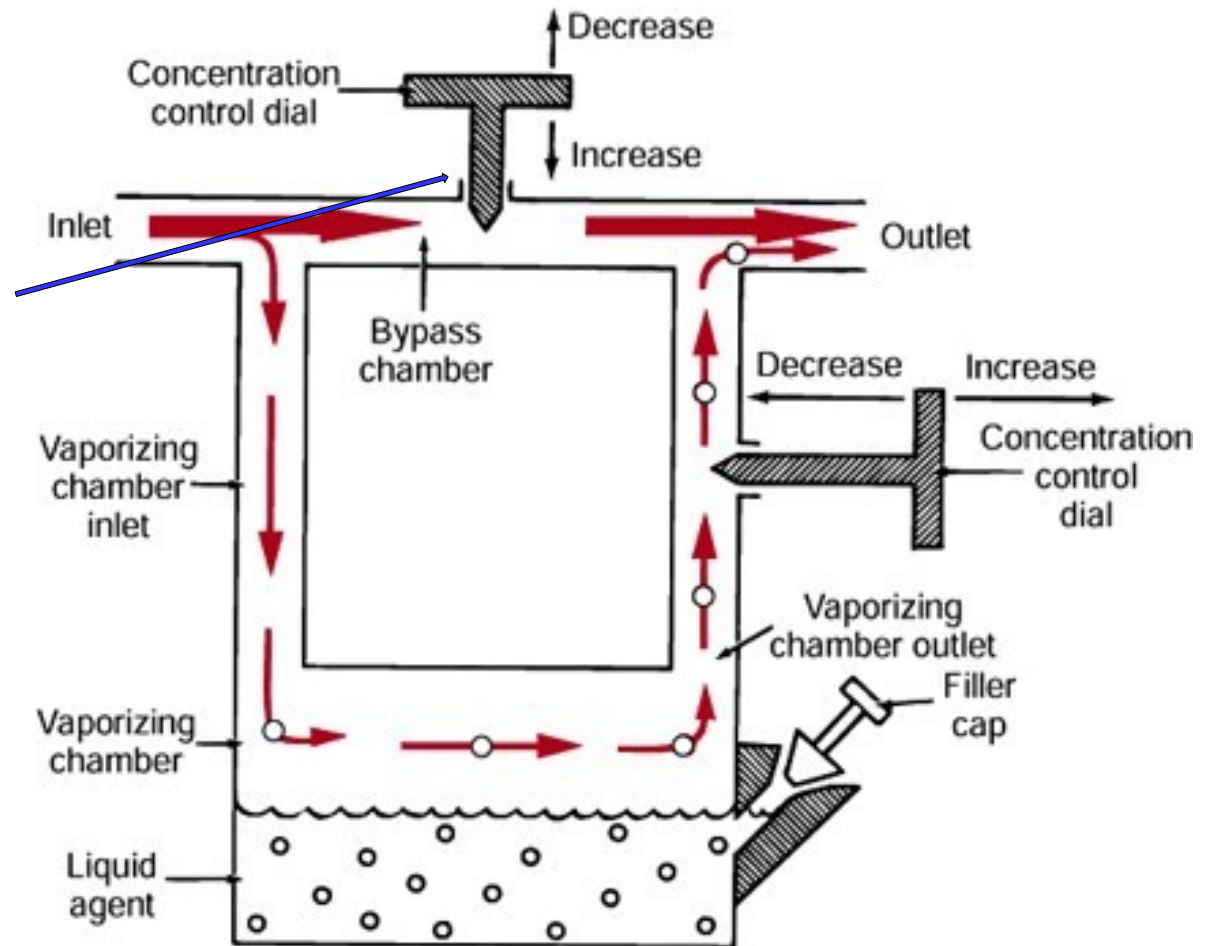
Vapor pressure of volatile agents at 20 °C (mmHg/kPa)

- Sevoflurane: 157 / 21
- Desflurane: 2369 / 31
- Enflurane: 1724 / 23
- Halothane: 243 / 32
- N₂O: 38,8 / 5

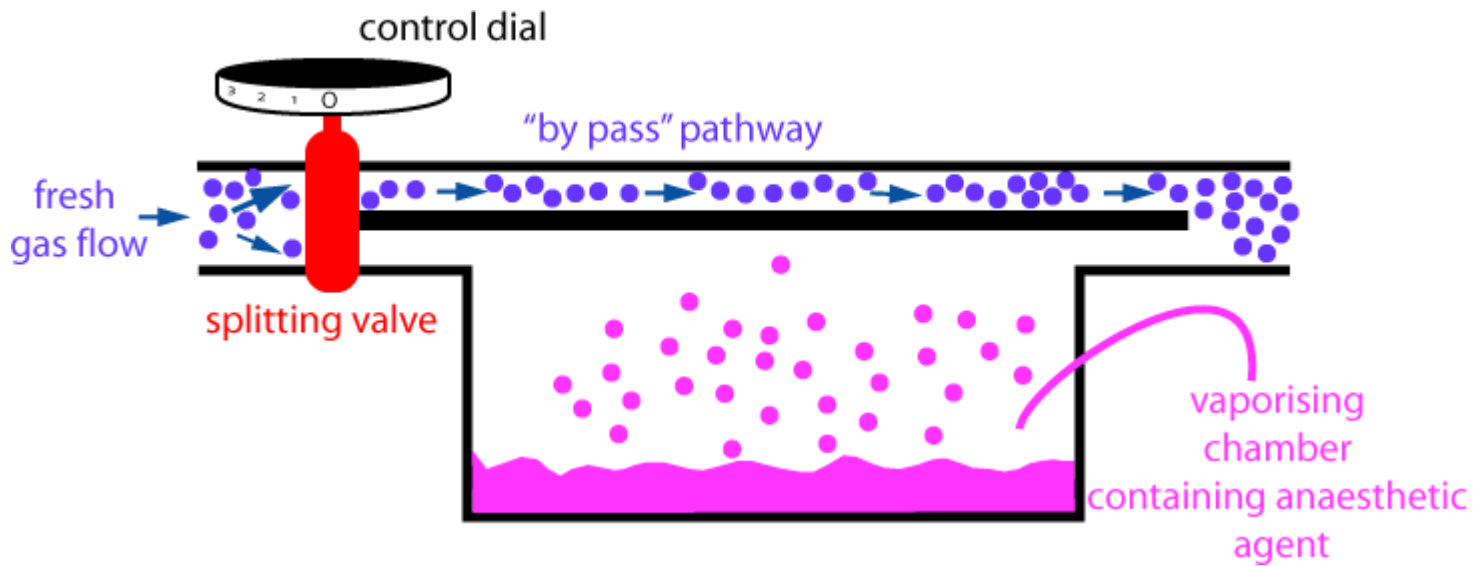
Vaporiser with variable bypass

(vapour splitting)

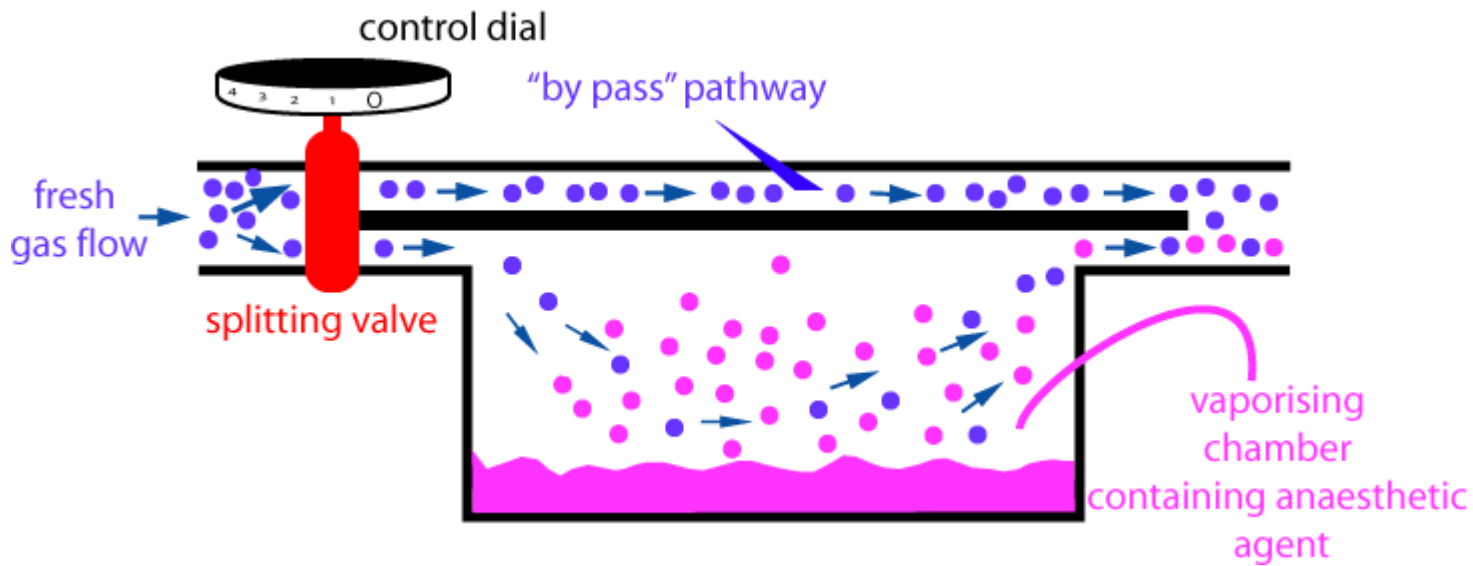
Splitting
ratio



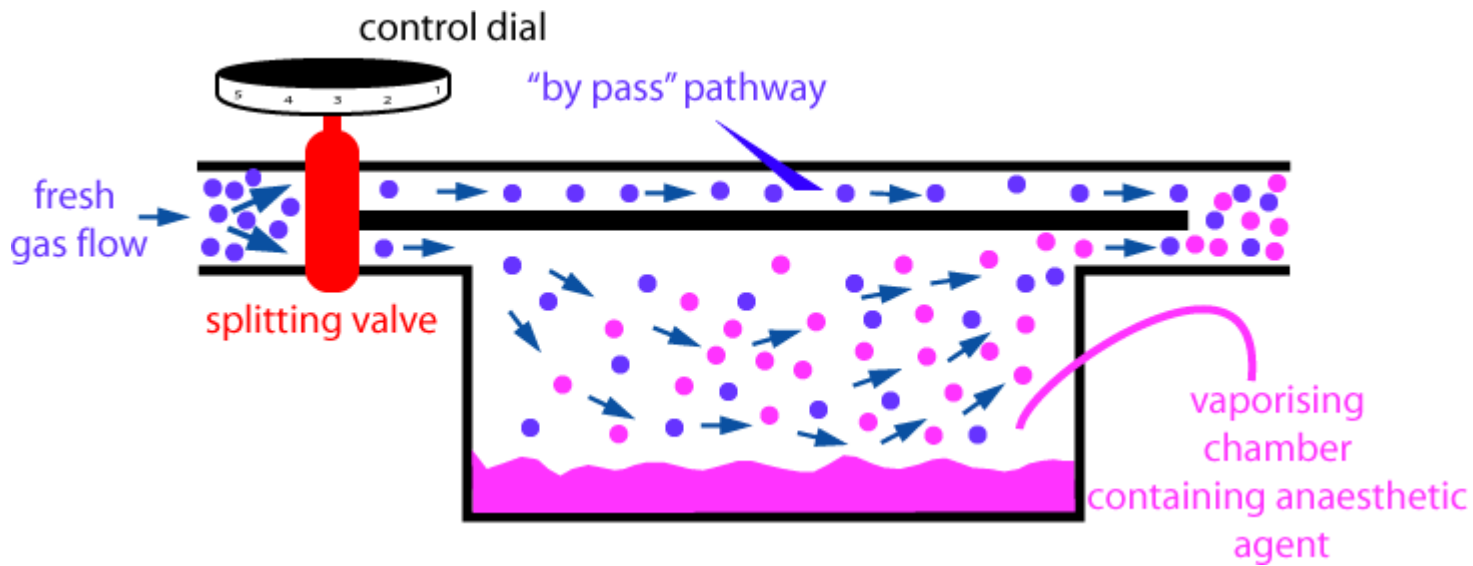
Variable bypass



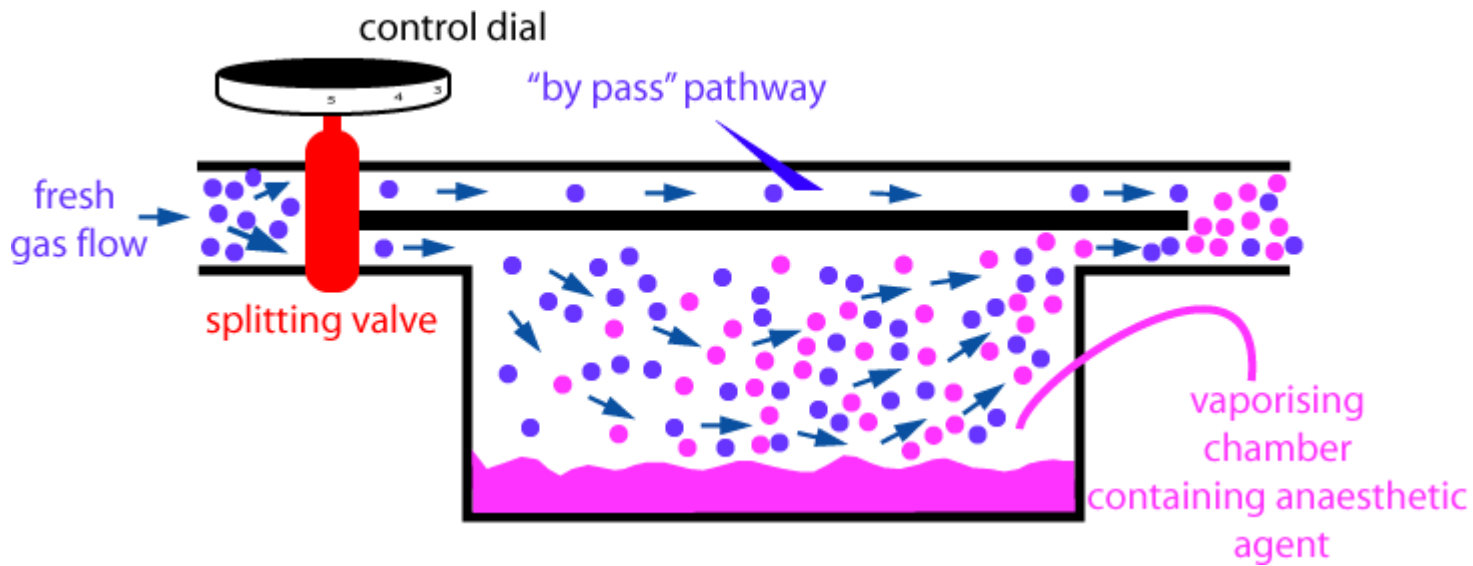
Variable bypass



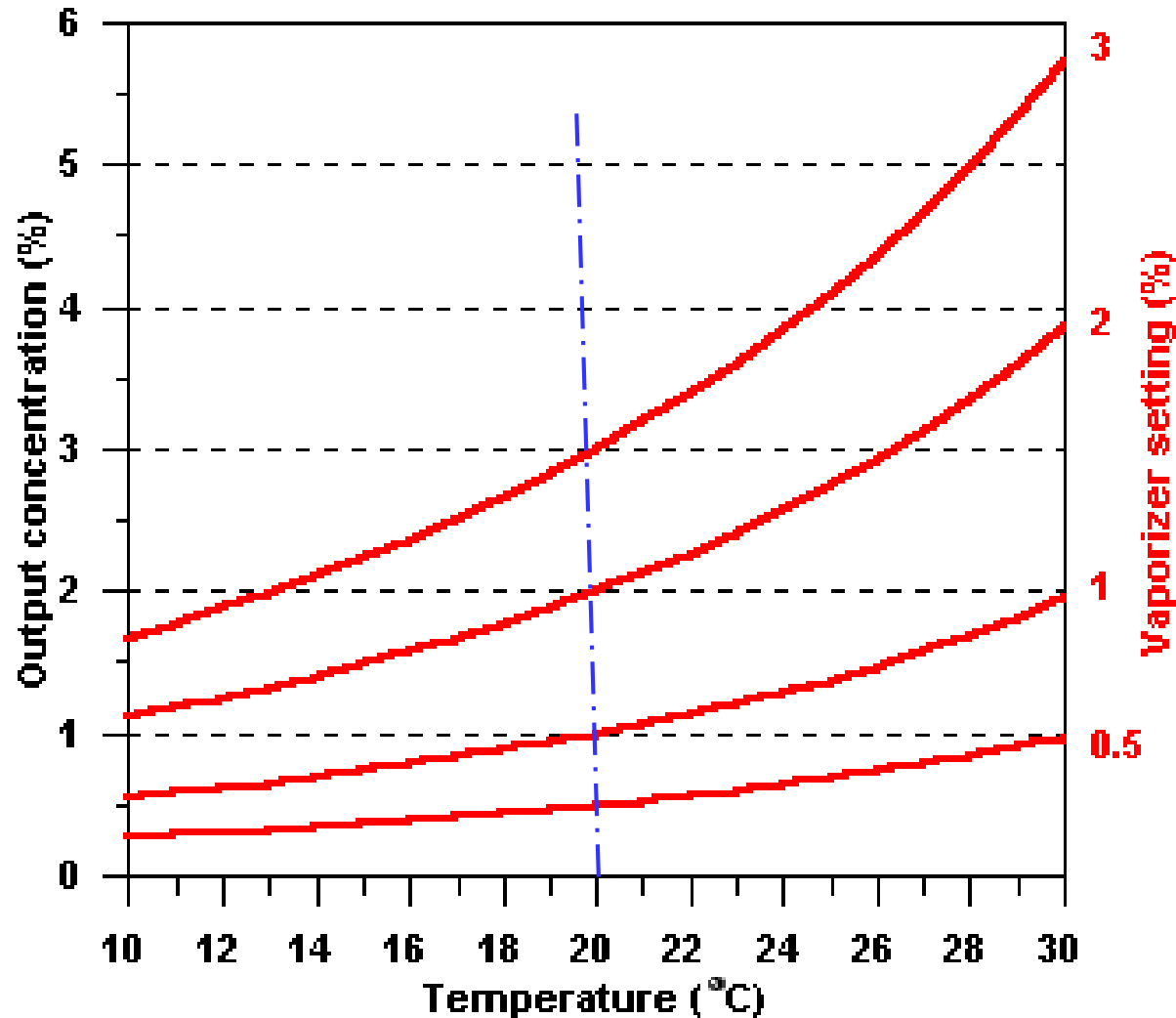
Variable bypass



Variable bypass

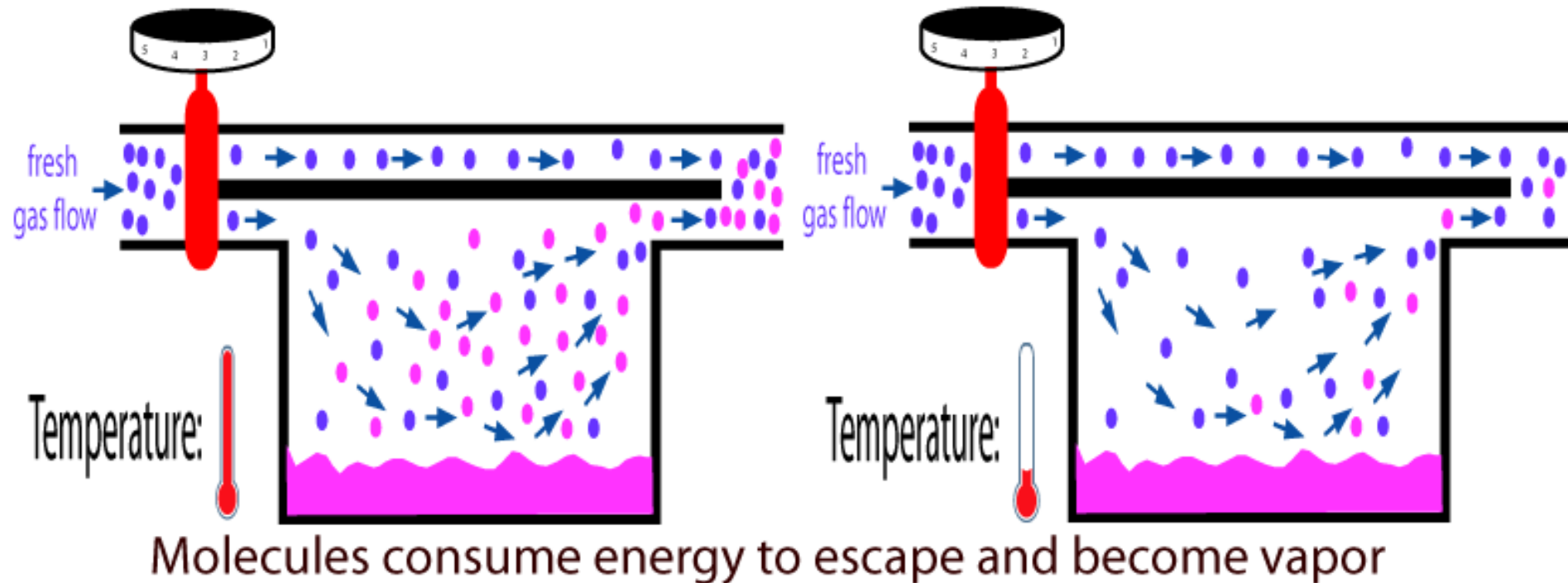


E. Temperature stability



Vaporizer
setting
at 20°C

According the stabilisation of temperature



conductivity

b) Temperature compensation

According the stabilisation of temperature



Temperature of anesthetic liquid

- fluctuations in ambient temperature
- loss due to latent heat of vaporization

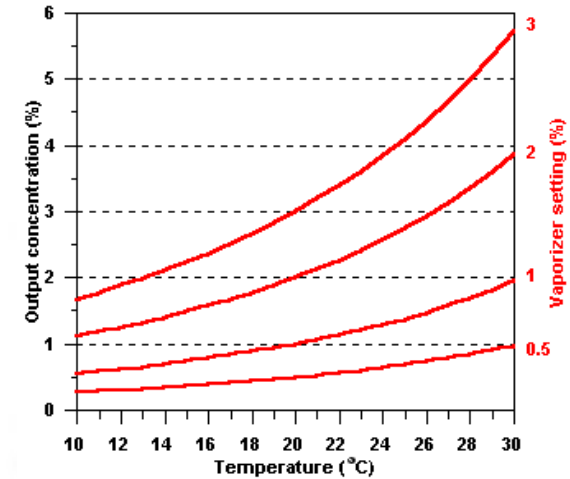
Solution

a) Temperature **stabilization**

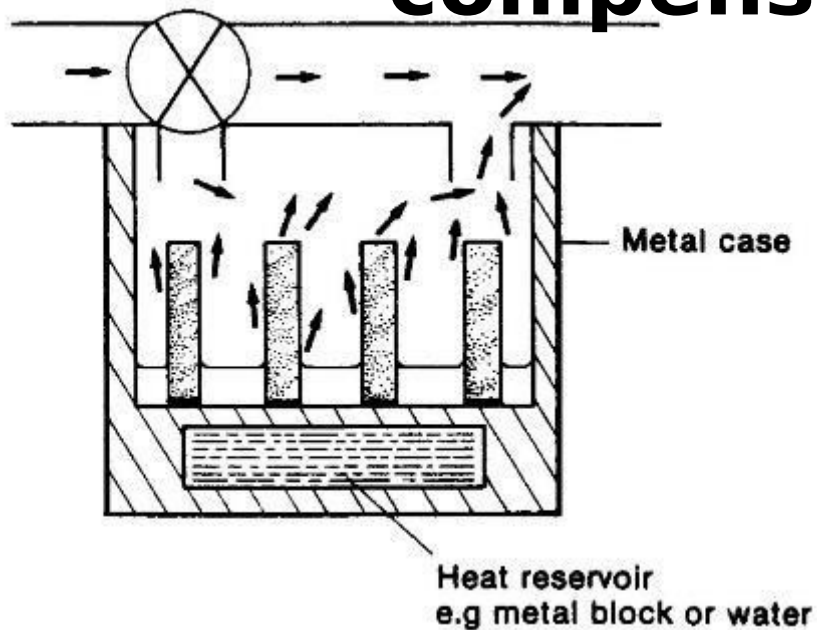
- high heat capacity, thermal conductivity

b) Temperature **compensation**

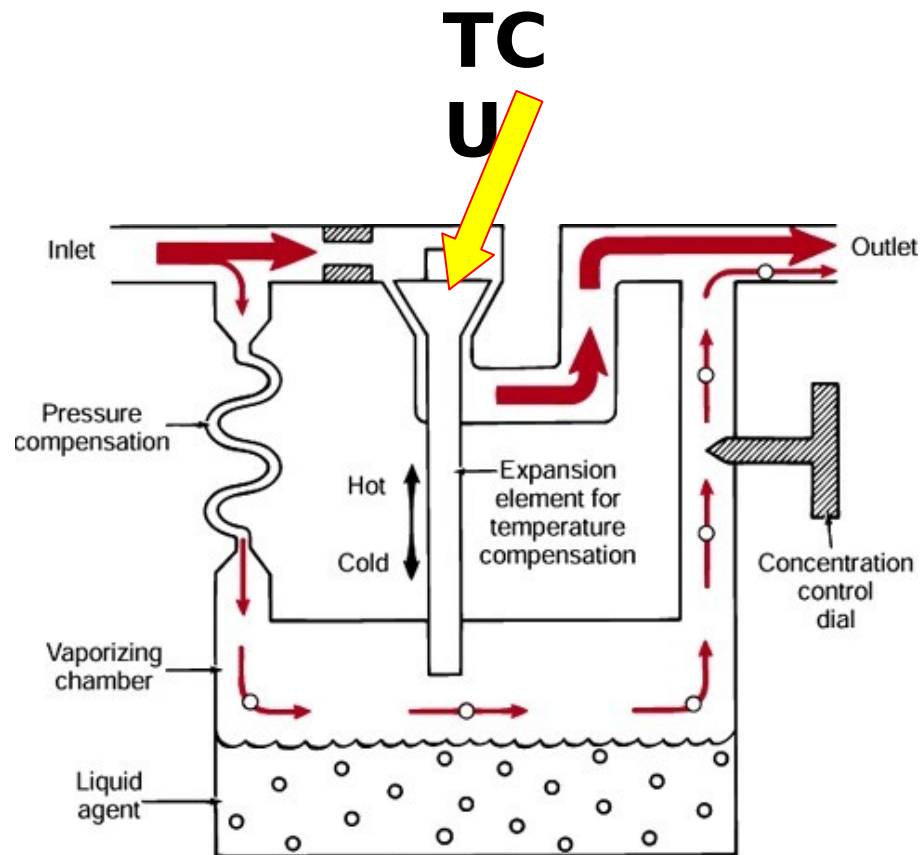
Correction to temperature



Temperature stabilisation / compensation (TCU)



Stabilizáci
a



F. According specificity

- a) Universal for all agents (older types)
- b) Agent specific (actual types)



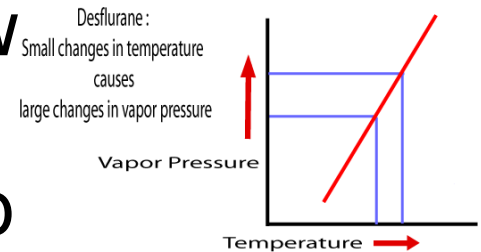
Most of the current vaporisers are:

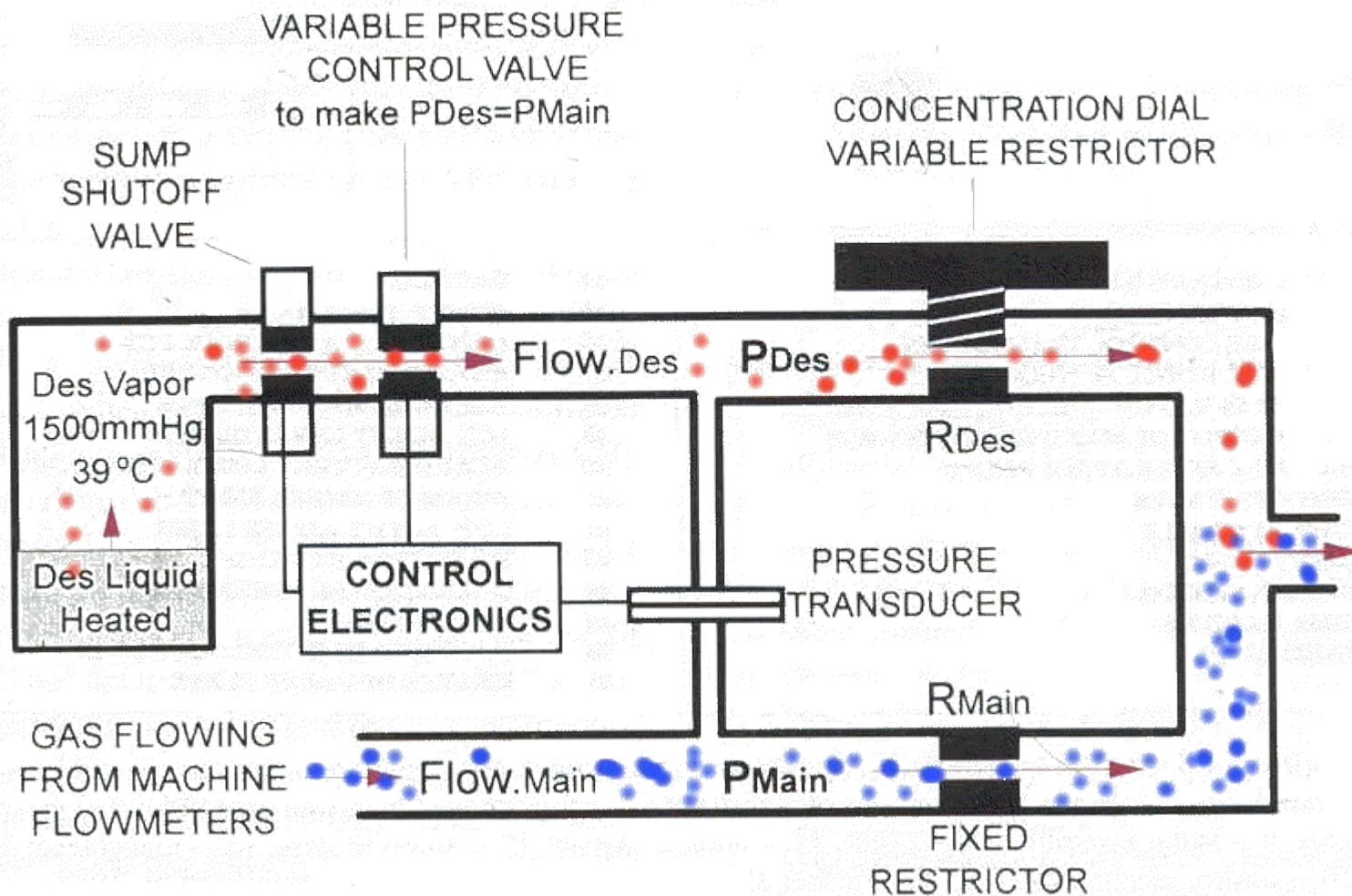
- flow-over/push-over
- variable bypass
- temperature compensated
- agent-specific
- out of circuit

Desflurane challenge



- Not suitable for variable bypass vaporiser
 - high SVP (88.5 kPa at 20 °C)
 - needs extreme bypass flow
 - low boiling point (23.5°C)
 - will boil, fluctuation of outp
- Solution:
 1. Warming to 39 °C; SVP to stable 194 kPa
 2. no bypass but DES injection to fresh gas flow
 3. Manual adjustment 0-12%; lock for 12-100%







G. Modificatory factors for the output of vaporiser



1. Precision (+/- 0.2 vol%), many factors
2. Flow (extreme values)
3. Composition of the carrier gas (N₂O)
4. Temperature (stability 15-36° C)
5. Atmospheric pressure (inversely)
6. Intermittent back flow (pump effect)

Flo w



- Higher flow – problem to achieve full saturation
- Maximalisation of surface area - wicks, baffles, cowls, nebulizers ...
- Modern vaporiser: stability in the range 0,25-15 l/min

Carrier gas composition

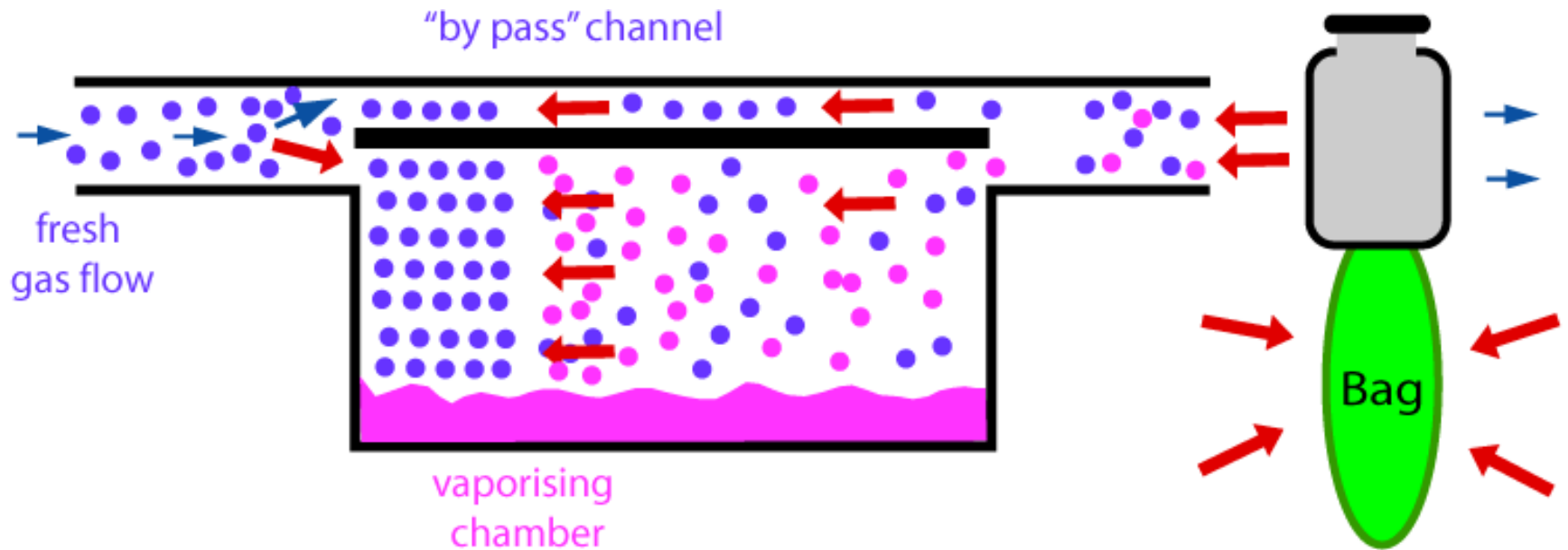
- Viscosities of air, N_2O < oxygen
- Splitting valve – decreased flow to vaporizing chamber
- Clinically not significant
- The same for Desflurane vaporiser

Backpressure



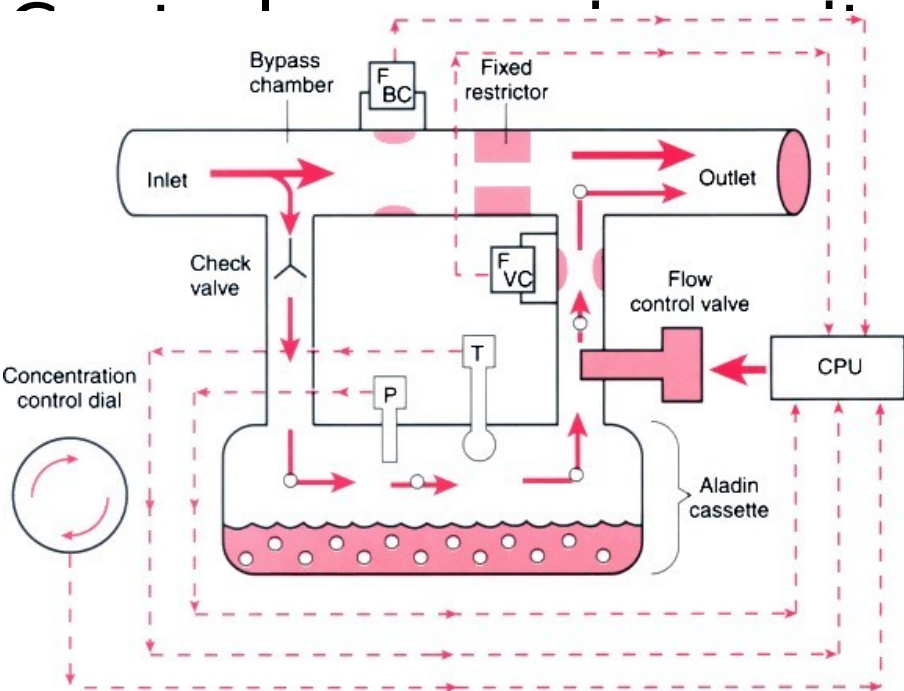
- Pumping effect
- Ventilator pressure transmitted retrograde to vaporiser
- Gas forced to vaporising chamber
 - resaturation of gas
 - saturated gas pressed into bypass channel
- Result: higher vapour concentration

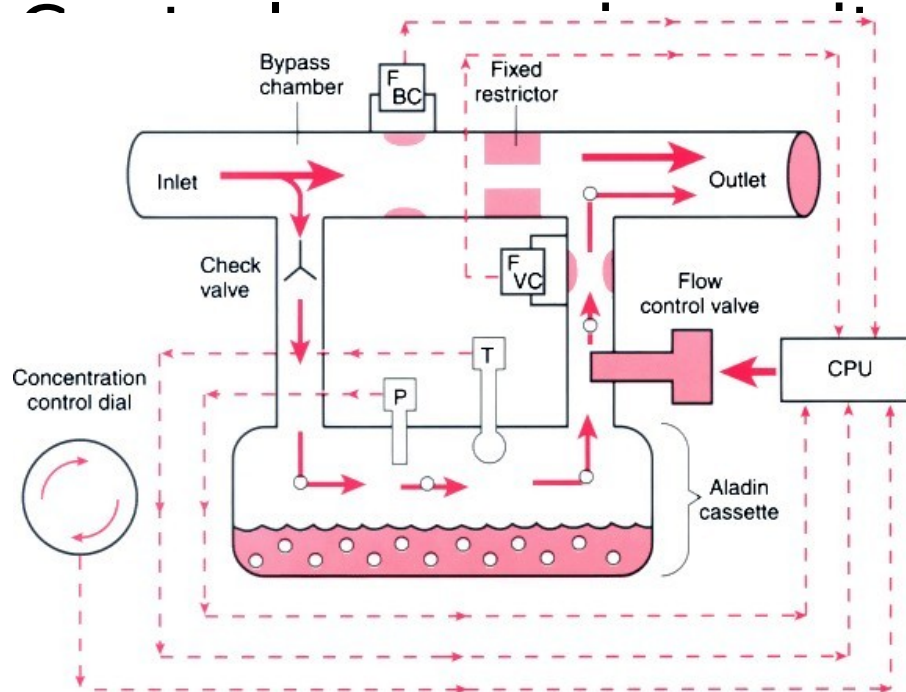
Backpressure re



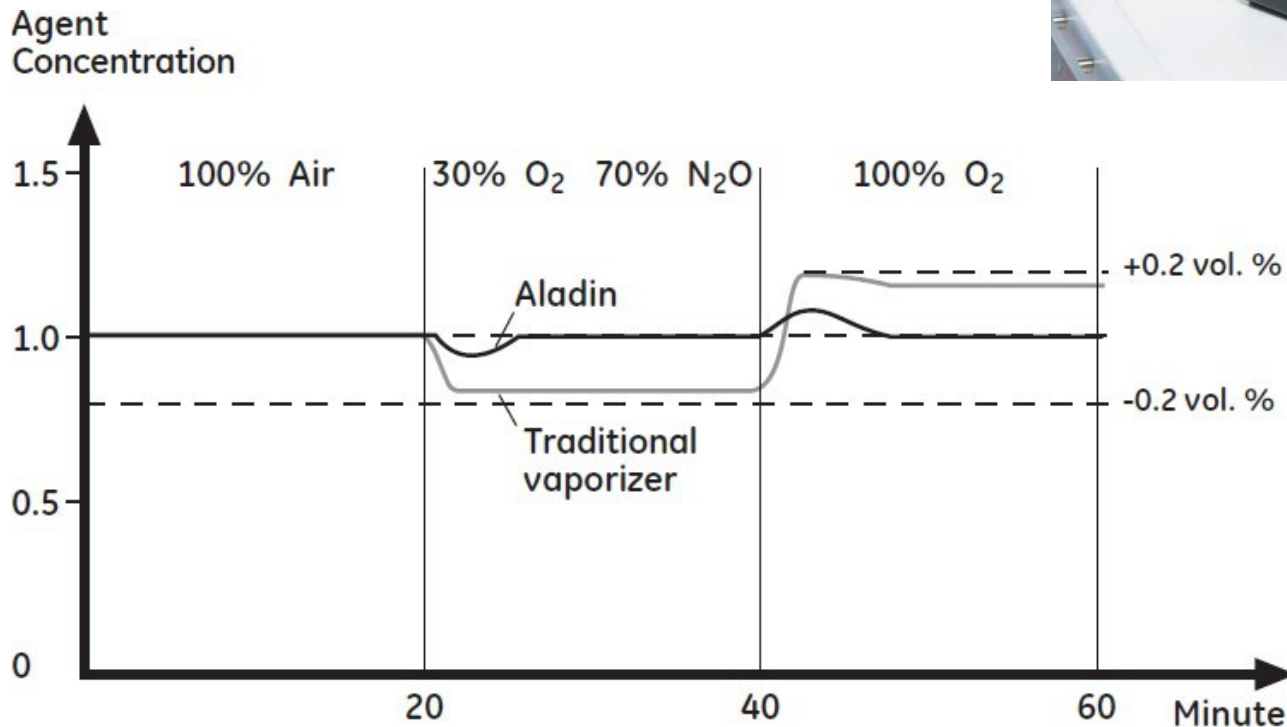
Aladin cassette vaporizer

- Datex Ohmeda, GE
- Agent specific vaporising chamber cassette

-  in anest.



Aladin casette

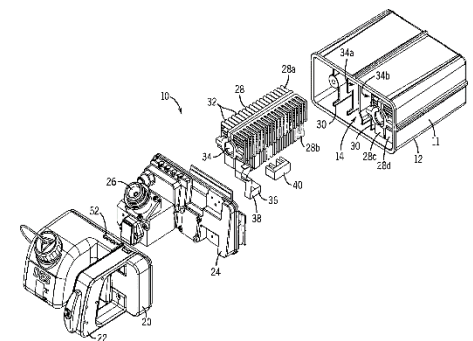


* Unlike conventional vaporizers, the Aladin Cassette is able to take into account the fresh gas flow concentrations due to the S/5 ADU's integrated electronic fresh gas flow measurement.

Advantages



- Variable bypass + measured flow
- Control valve with adjustment to flow
- Measurement of
 - bypass flow
 - liquid temperature
 - chamber pressure
- Synthetic lamellae with metal plates (wick)
- Temperature stabilization (metal plates, fan)
- Carrier gas identification
- No backpressure problem



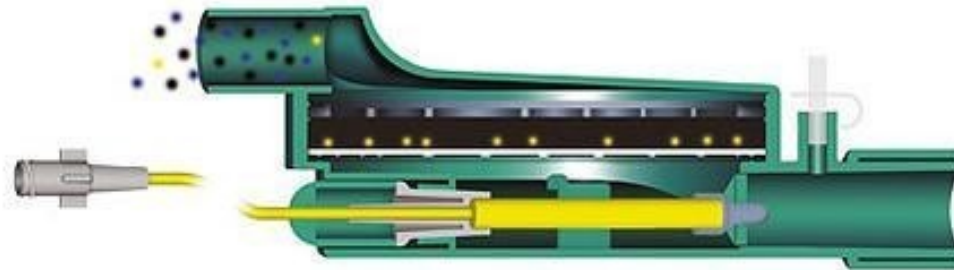
Carestation



Anaconda - vaporiser for sedation

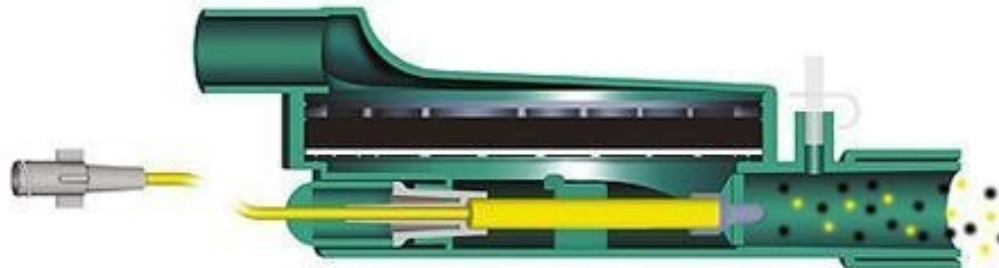
Expiration

Air/oxygen and CO₂ passes the active carbon out into the ventilator circuit and out through the ventilator exhaust. The anaesthetic agent is adsorbed to the active carbon.



Inspiration

During inspiration the anaesthetic agent is desorbed and transported with the air/oxygen to the patient, together with agent evaporated from the evaporator.



- Air/oxygen
- Anaesthetic agent

Safety first; concerns



- Incorrect agent
- More than one vaporizer being used
- Reversal insertion of vaporizer
- Tilting and overfilling of vaporizer
- Leakage
- Electronic failure

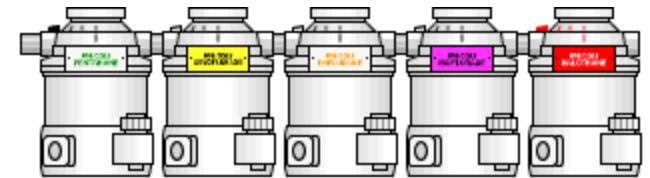
Safety first; measures



1. ISO/DP 5350 Norm for colour coding
2. Geometric coded filling devices
3. Interlock system to prevent more than one vaporizer being used (accidental overdose)
4. Carefull manipulation
5. Checklist for anaesthesia equipment (HD)

Colour coded filling devices

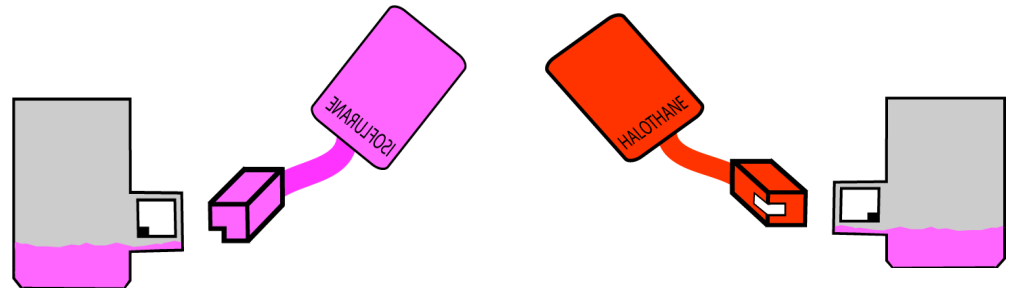
Anesthetic	Colour
Halotane	red
Isoflurane	purpur
Enflurane	orange
Sevoflurane	yellow
Desflurane	blue



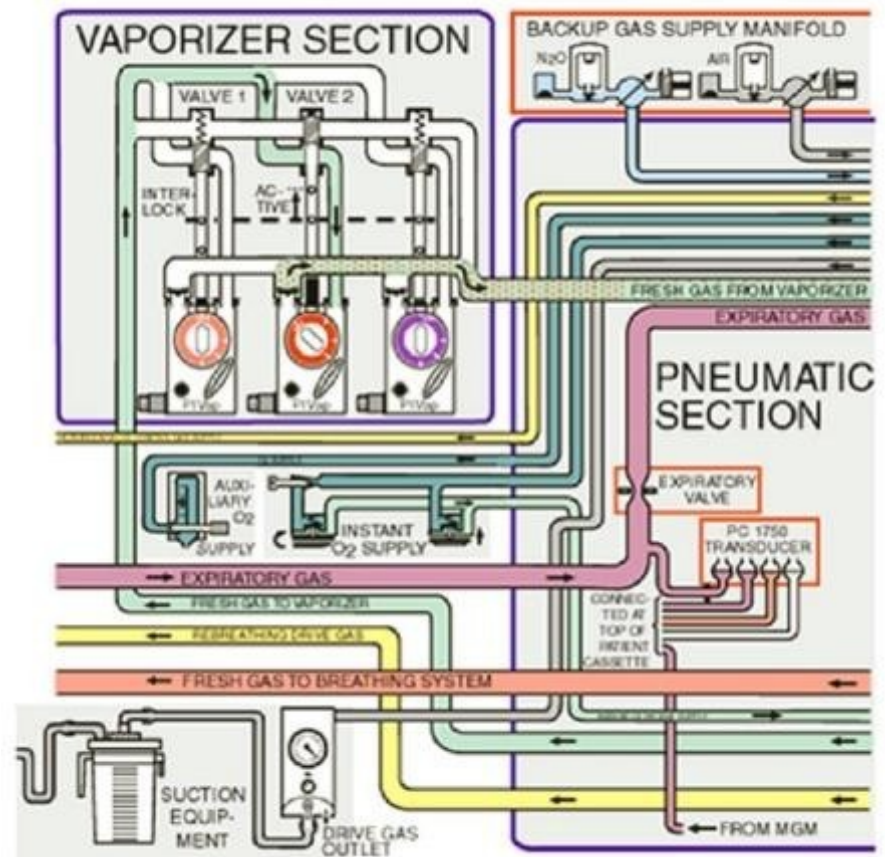
Methoxyflurane Sevoflurane Enflurane Isoflurane Halothane



Funnel / keyed filler types



More agents?

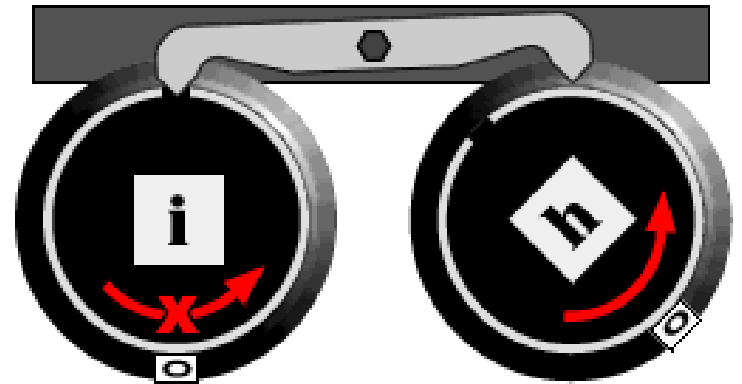
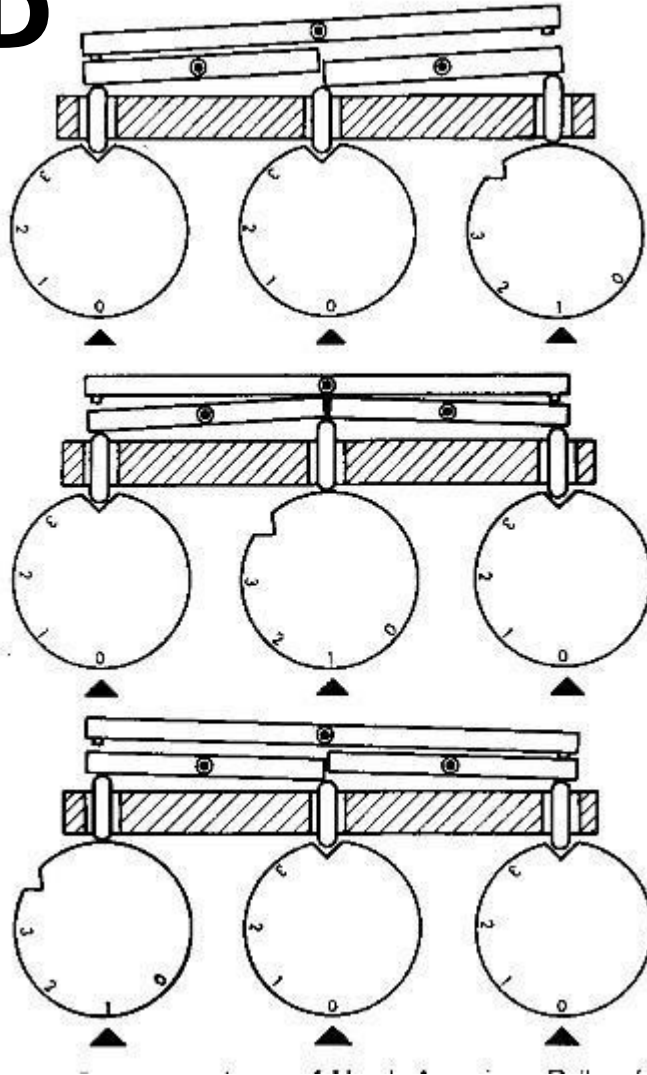


The vaporizer interlock ensures that

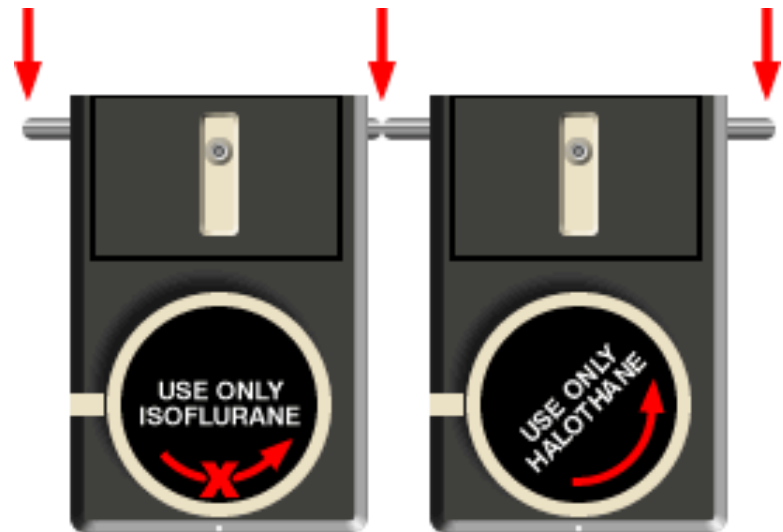
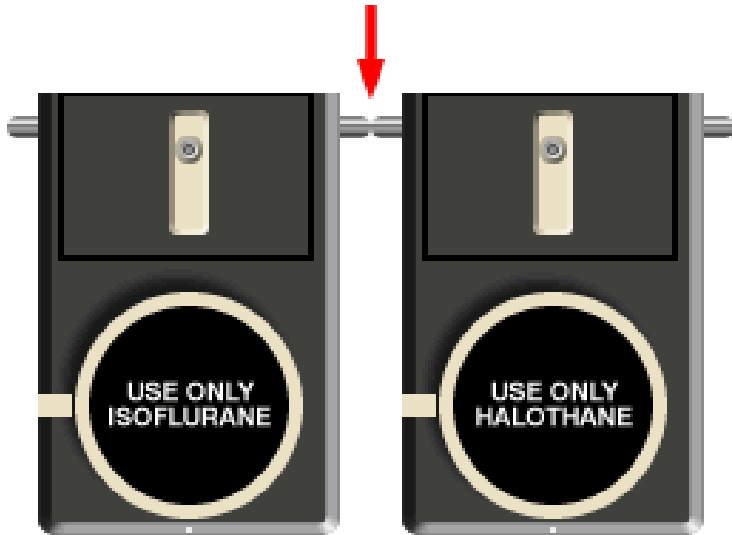


- Only one vaporizer is turned on
- Gas enters only the one which is on
- Trace vapor output is minimized when the vaporizer is off
- Vaporizers are locked into the gas circuit, thus ensuring they are seated correctly.

Interlock NAD



Interlock



Maintenan

ce

Every Two Weeks:

The vaporizer should be drained into an appropriately marked container when the agent level is low and the agent discarded. Less frequent intervals may be used when the anesthetic agent does not contain additives or stabilizing agents.

Annually:

The vaporizer should be serviced at an authorized service center. This service should include:

- 1) Complete disassembly of components.
- 2) Inspection of all parts for damage and wear.
- 3) Thorough cleaning of all metal parts.
- 4) Replacement of wicks, seals and damaged, worn or outdated items.
- 5) Lubrication where necessary.
- 6) Re-assembly of vaporizer and testing for and correction of any leaks.
- 7) [Verification of the delivered vapor concentrations](#) at different



Checklist for Anaesthetic Equipment 2012

AAGBI Safety Guideline



Checks at the start of every operating session

Do not use this equipment unless you have been trained

Check self-inflating bag available

Perform manufacturer's (automatic) machine check

Power supply

- Plugged in
- Switched on
- Back-up battery charged

Gas supplies

- Gas and vacuum pipelines – 'tug test'
- Cylinders filled and turned off
- Flowmeters working (if applicable)
- Hypoxic guard working

Breathing system

- Whole system patent and leak free using 'two-bag' test
- Vaporisers – fitted correctly, filled, leak free, plugged in (if necessary)
- Soda lime - colour checked
- Alternative systems (Bain, T-piece) – checked
- Correct gas outlet selected

Monitors

- Working and configured correctly
- Alarms limits and volumes set

Airway equipment

- Full range required, working, with spares

RECORD THIS CHECK IN THE PATIENT RECORD

Don't Forget!

- Self-inflating bag
- Common gas outlet
- Difficult airway equipment
- Resuscitation equipment
- TIVA and/or other infusion equipment

Summary - vaporiser

- Anaesthesiologist has to be familiar with principles and instructions for use
- Modern vaporisers are agent specific, plenum, with variable bypass, temperature compensated.
- New generation: meeting all potential problems
- Draw over: low resistance, in circuit, less efficient; but robust, portable, suitable for „field anaesthesia“.

Futur

e



- New inhalation agents?
- Low flow
- Closed circuit, no flow
- Computer assisted
- Anaesthesia machine integrated
- Patient adapted, feedback
- Closed loop



**Thank
you**