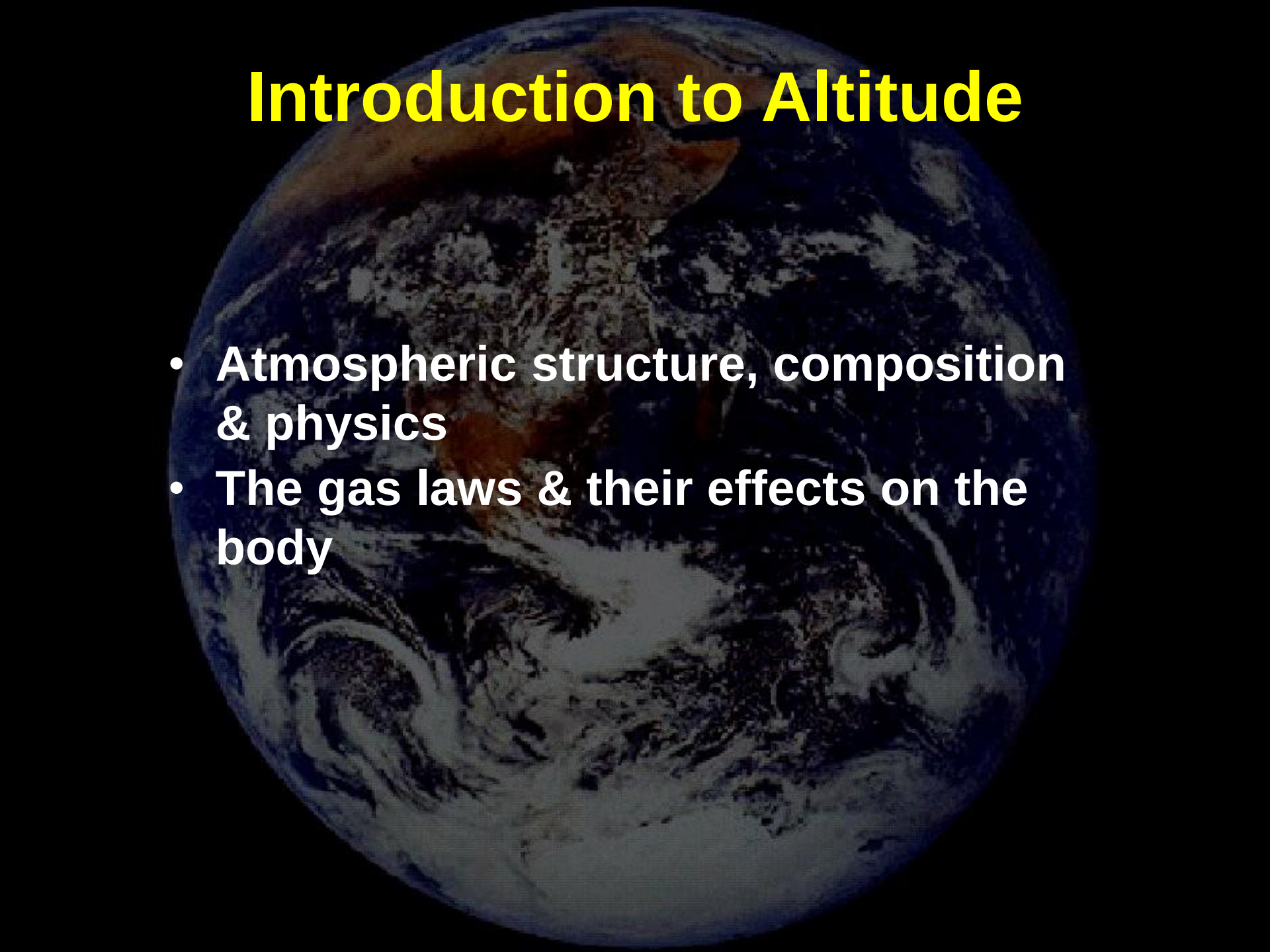
Wing Commander Alec Hurley RAF(ret)

Late Chief Instructor in Aviation Medicine & Officer Commanding Altitude Medicine & Clinical Support

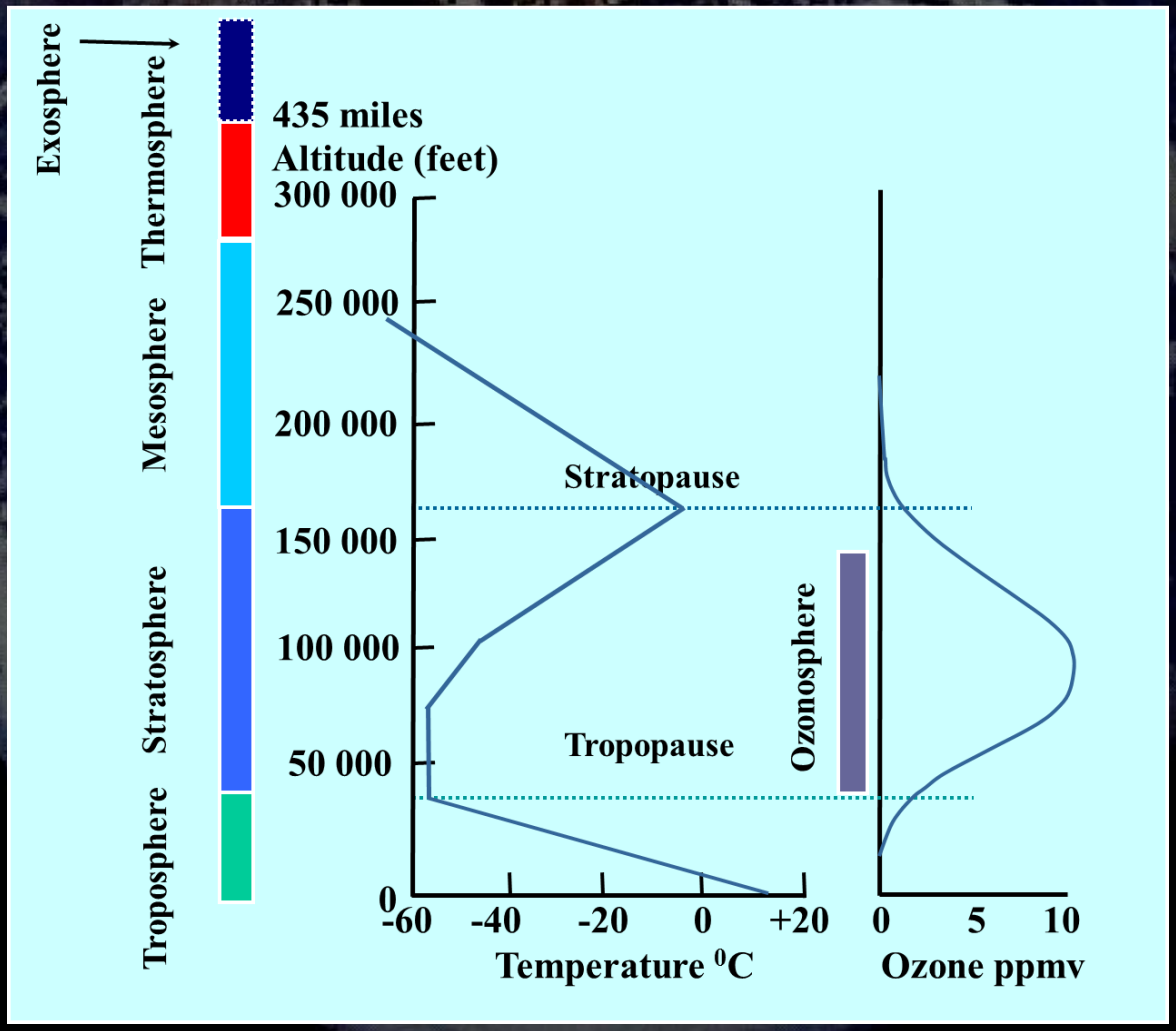
RAF Centre of Aviation Medicine RAF Henlow

Introduction to Altitude



- Atmospheric structure, composition & physics
- The gas laws & their effects on the body

Temperature & Layers of the Atmosphere



Composition of the Atmosphere

Ground Level		Top of Everest?	
Nitrogen	78.09%	Nitrogen	78.09%
Oxygen	20.95%	Oxygen	20.95%
Argon	0.93%	Argon	0.93%
Carbon Dioxide	0.03%	Carbon Dioxide	0.03%
Rare Gases	Trace	Rare Gases	Trace

ATMOSPHERE

ICAO Standard Atmosphere (1964)

(ICAO - International Civil Aviation Organisation UN)

- Dry, dust free air
- Stated gas composition
- Atmospheric pressure at sea level 760 mmHg
- Relative molecular mass of air at sea level 28.96
- Temperature of 15^0C at sea level
- Adiabatic lapse rate of 1.98^0C/1000 ft (0-36,000 ft)
- Acceleration due to gravity constant at 9.8 m/s^2

ATMOSPHERE

- Temperature decreases by 1.98^{o}C per 1000 feet
- Atmospheric pressure decreases to half the sea level value by 18 000 feet reducing the amount of available Oxygen
- With ascent the relative percentage of oxygen remains constant but the relative pressure decreases

The Gas Laws

- Boyle's law
- Charles's law
- Universal gas law
- Dalton's law of partial pressures
- Henry's law

Boyle's Law

Robert Boyle

1627 - 1691

At a constant temperature the volume of a given mass of gas is inversely proportional to the pressure to which it is subjected

$$P_1 / P_2 = V_2 / V_1$$

Charles's Law

J A C Charles 1746 - 1823

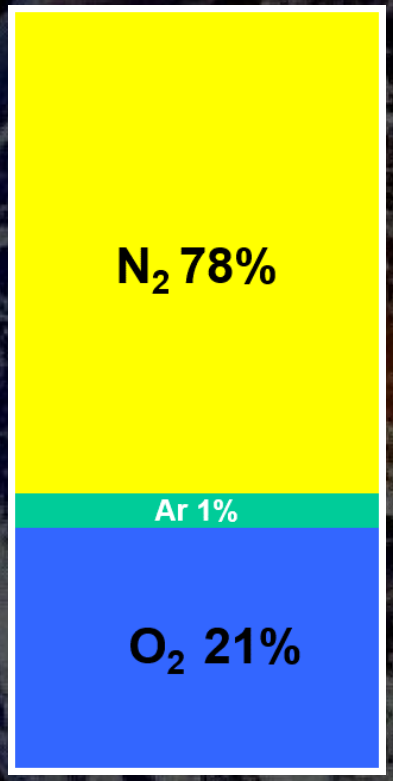
The volume of a given mass of gas at constant pressure is directly proportional to its absolute temperature

$$V_1 / V_2 = T_1 / T_2$$

Universal Gas Law

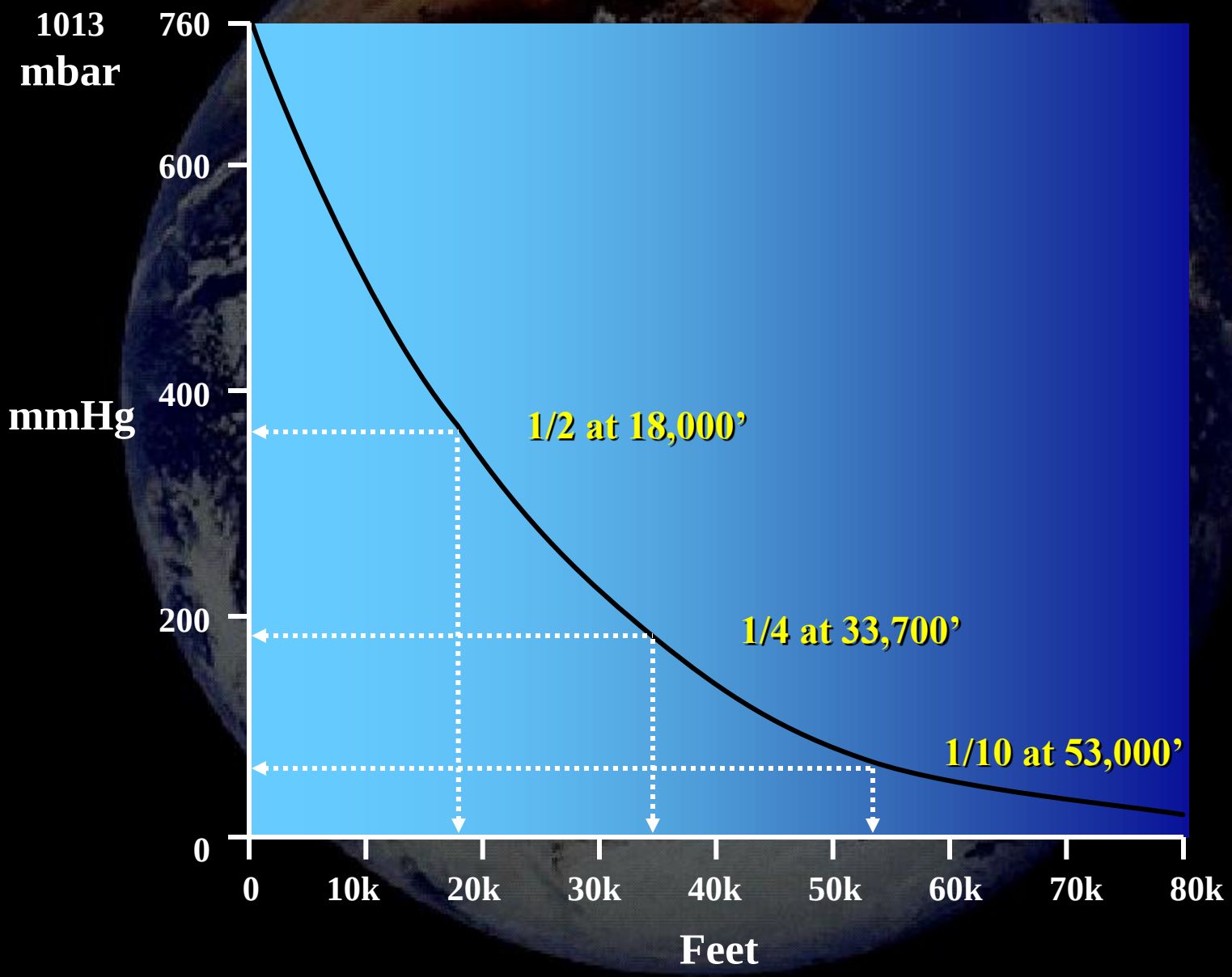
$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Composition of the Atmosphere

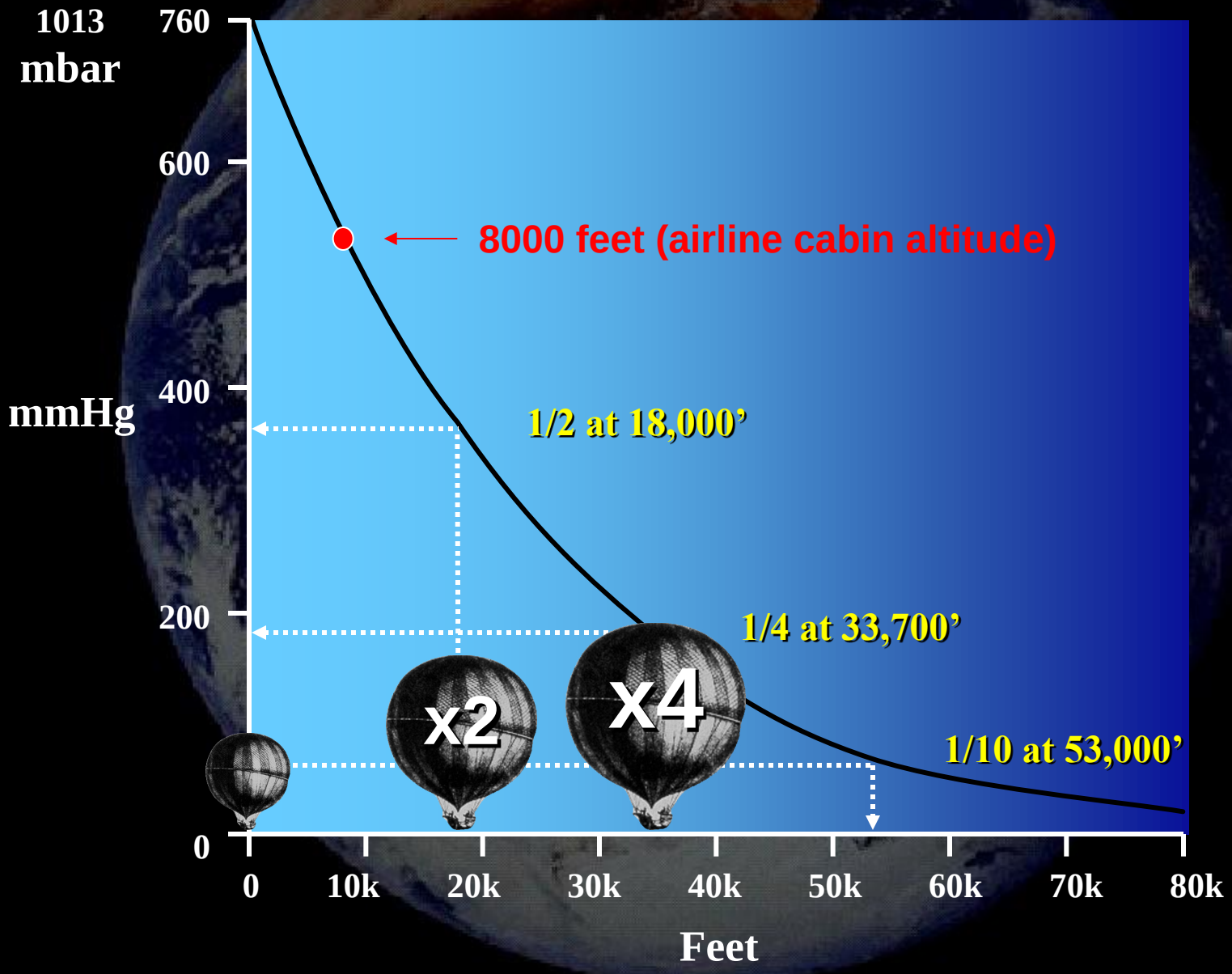


- Atmospheric composition relatively constant between sea level & 300,000ft
  - Oxygen (O_2) 21%
  - Nitrogen (N_2) 78%
  - Argon (Ar) ~1%
  - Carbon dioxide (CO_2) 0.03%
  - Trace gases

Physics of the Atmosphere

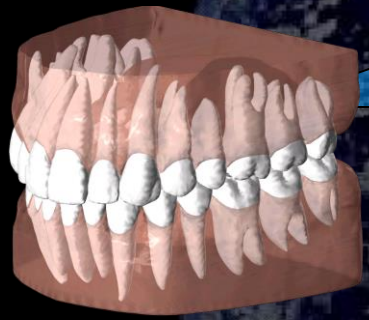


Boyle's Law

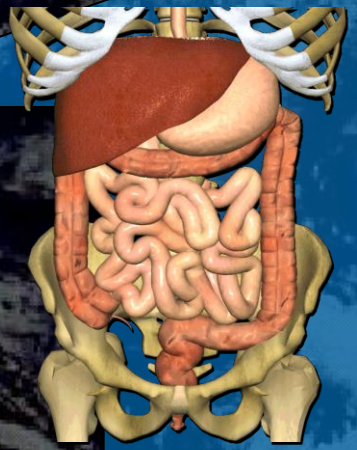

1013 mbar
760
600
400
200
0
mmHg
8000 feet (airline cabin altitude)
1/2 at 18,000'
1/4 at 33,700'
1/10 at 53,000'
x2
x4
0
10k
20k
30k
40k
50k
60k
70k
80k
Feet

Effects of Pressure Changes

On Ascent

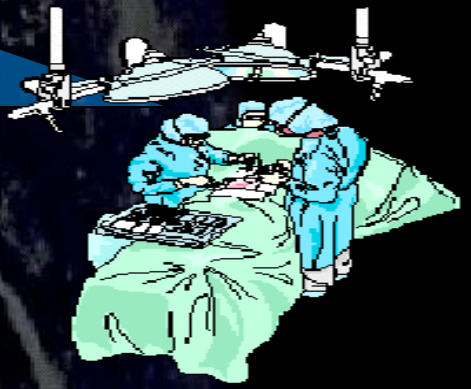


Teeth



Guts

Lungs



Post-surgery

Effects of Pressure Changes

On Descent

Sinuses

Middle ear

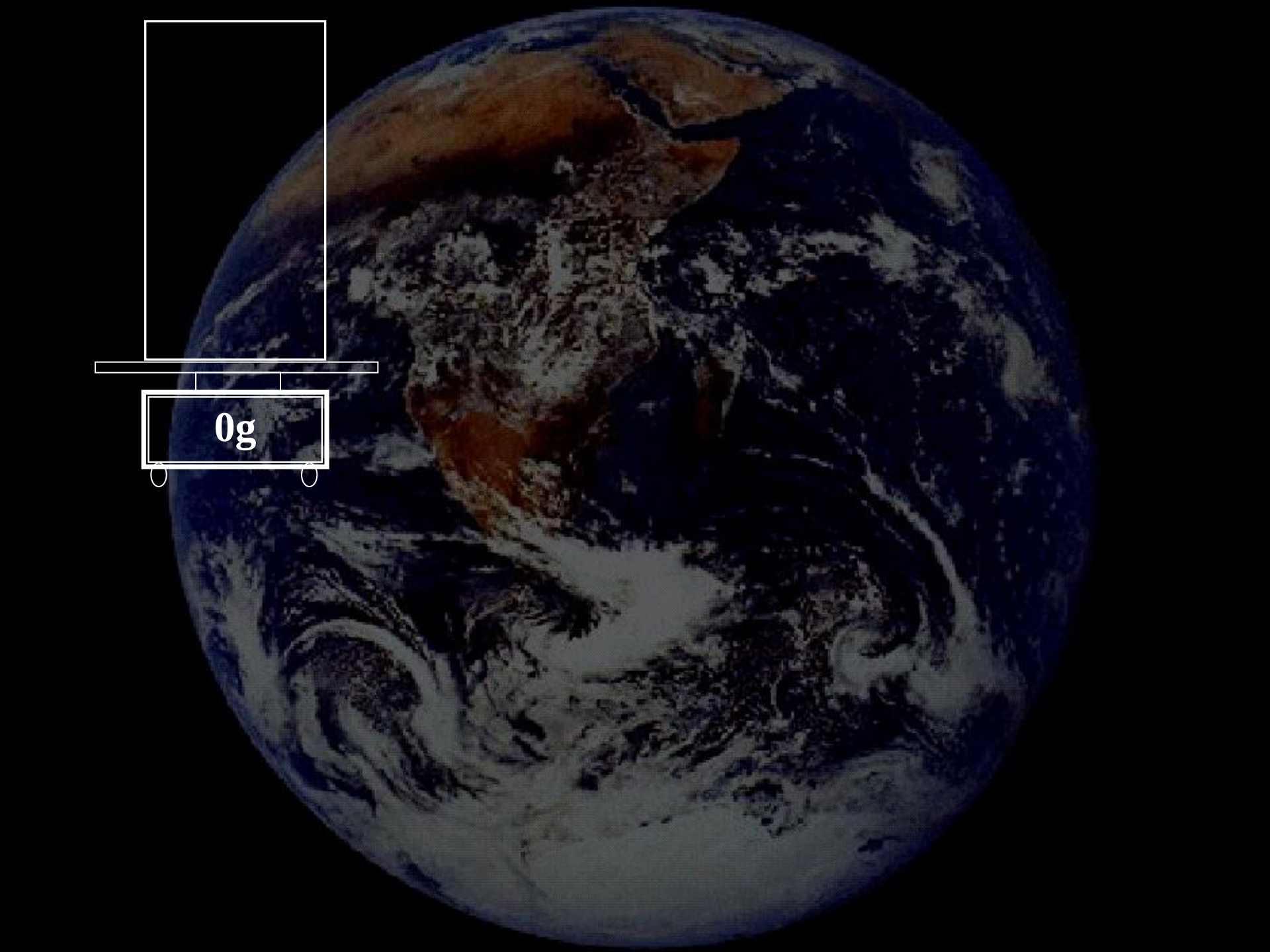
Dalton's Law of Partial Pressures

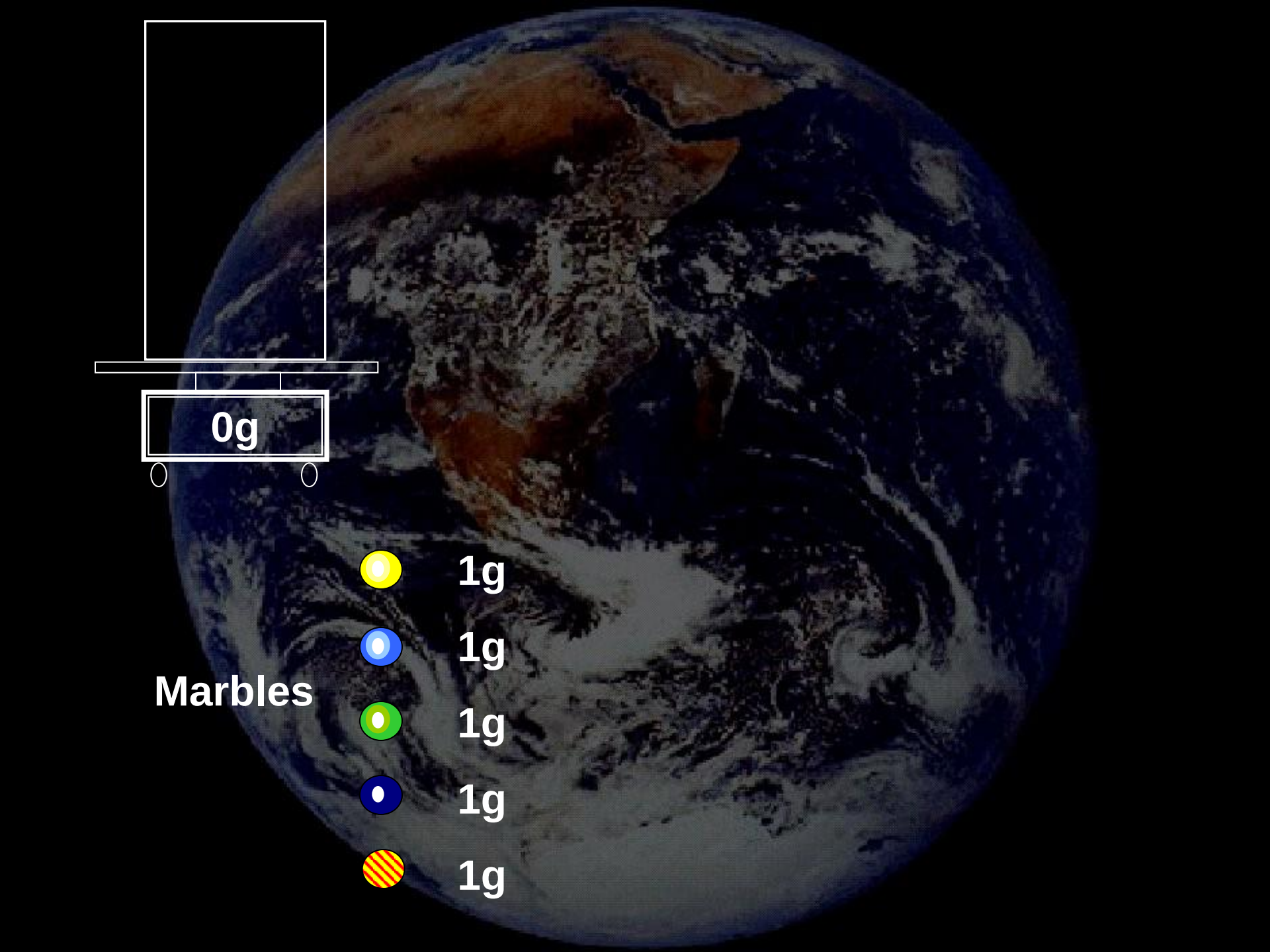
John Dalton
1766-1844

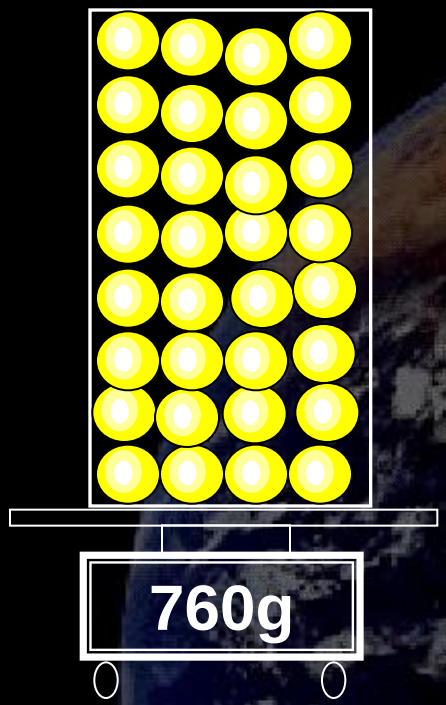
- Pressure exerted by a mixture of gases is equal to the sum of the pressures each would exert if it alone occupied the space

$$P_{total} = P_1 + P_2 + P_3 \ldots + P_n$$

- Termed *partial pressures*


0g


0g
Marbles
1g
1g
1g
1g
1g



760 yellow marbles

Marbles

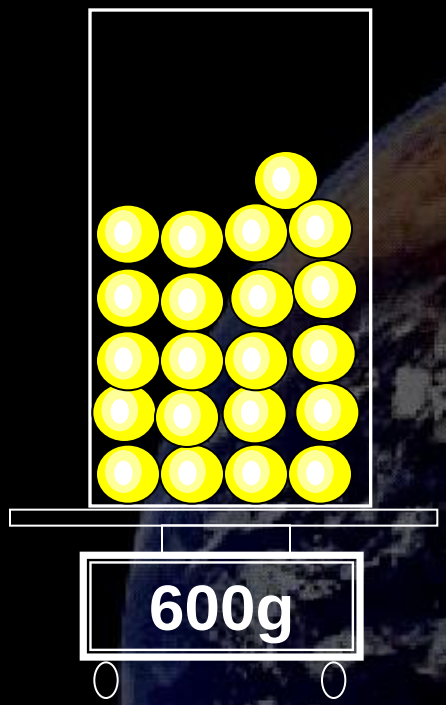
1g

1g

1g

1g

1g



600 yellow marbles

Marbles

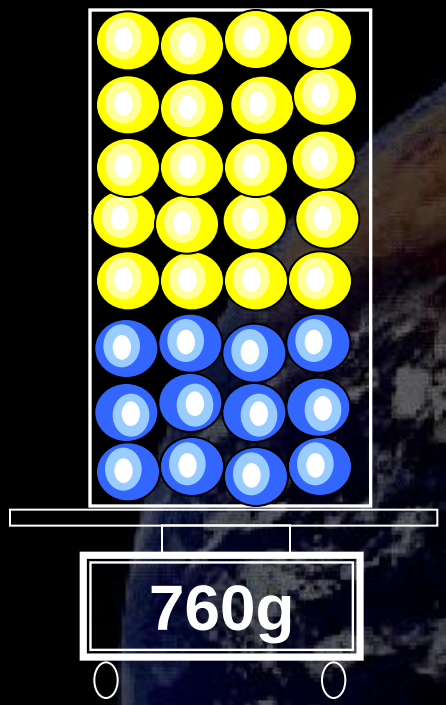
1g

1g

1g

1g

1g



600 yellow marbles

160 blue marbles

Marbles

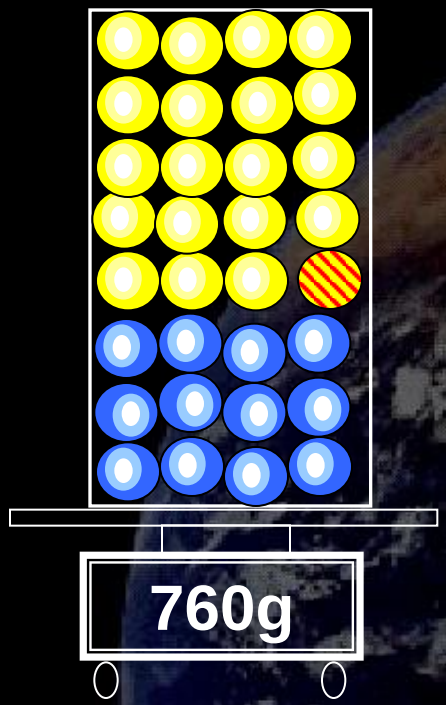
1g

1g

1g

1g

1g



599 yellow marbles

1 stripy marble

160 blue marbles

Marbles

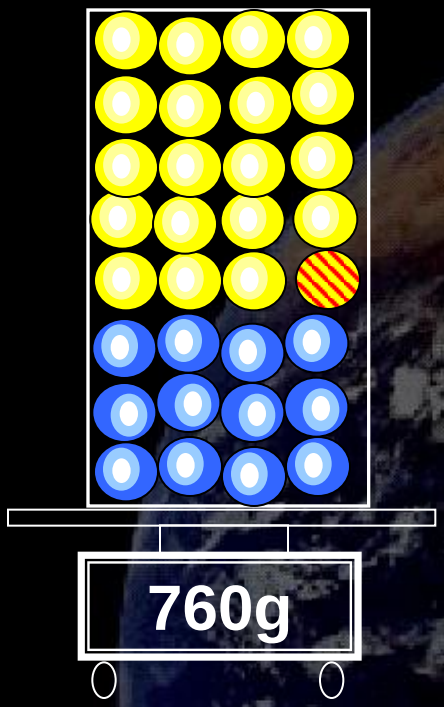
1g

1g

1g

1g

1g



599 yellow marbles

1 stripy marble

160 blue marbles

569 yellow

1 stripy

103 blue

40 green

47 navy blue

Marbles

1g

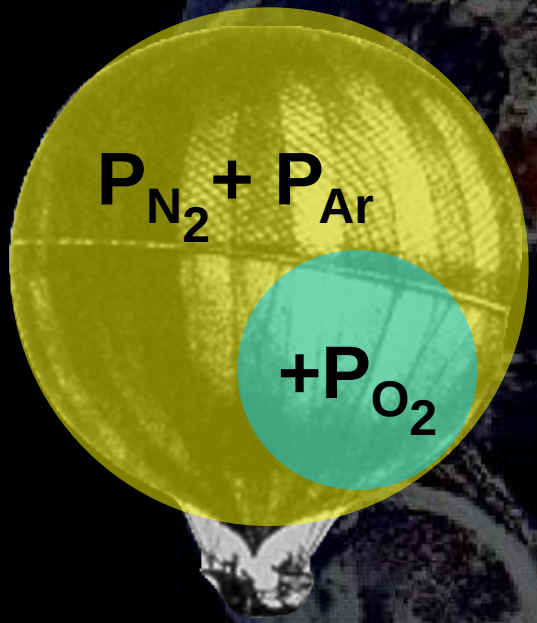
1g

1g

1g

1g

Dalton's Law of Partial Pressures



- **The partial pressure of any gas in a mixture is given by:**

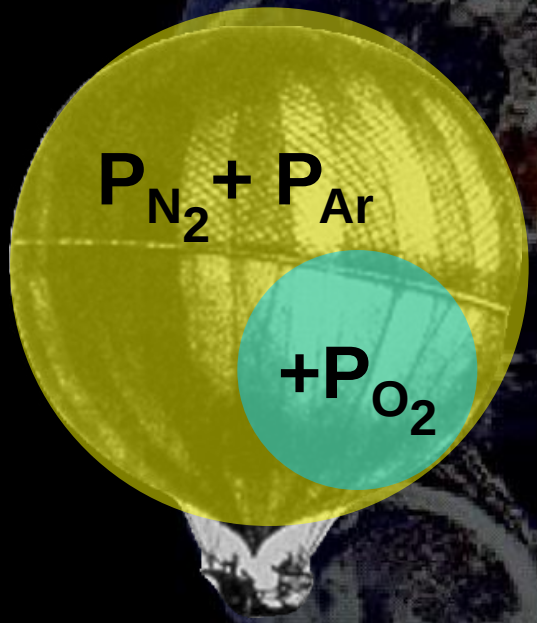
$$P_x = F_x \times P_{total}$$

P_x = Gas in question

F_x = The fractional percentage of that Gas_x

P_{total} = Total Pressure of all Gases

Dalton's Law of Partial Pressures



Air Pressure 760 mmHg (Sea Level)

- **The partial pressure of *oxygen* in air given by:**

$$P_{O_2} = \frac{21\% \times 760\ mmHg}{100} = 160mmHg$$

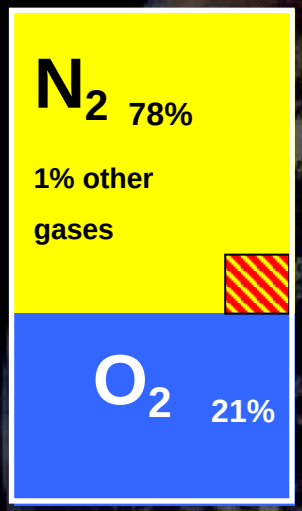
Hypoxia

Paul Bert

1833 - 1886

- Inadequate oxygen supply in body or tissues

Gas Composition at Sea Level



600 mmHg

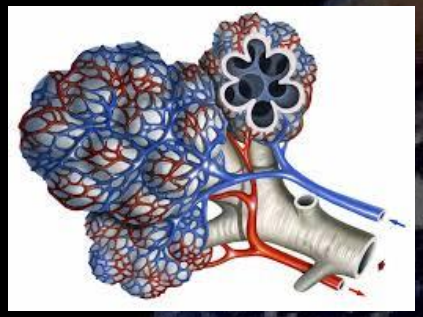
160 mmHg

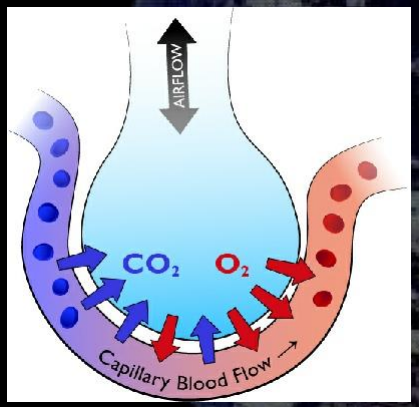
760 mmHg

Gas

- Nitrogen N_2
- Oxygen O_2
- Other Gases (Argon)

Alveolar Gas Equation





$$PI_{O_2} - PA_{O_2} = PA_{CO_2} \cdot \left(F I_{O_2} + \frac{1 - F I_{O_2}}{R} \right)$$

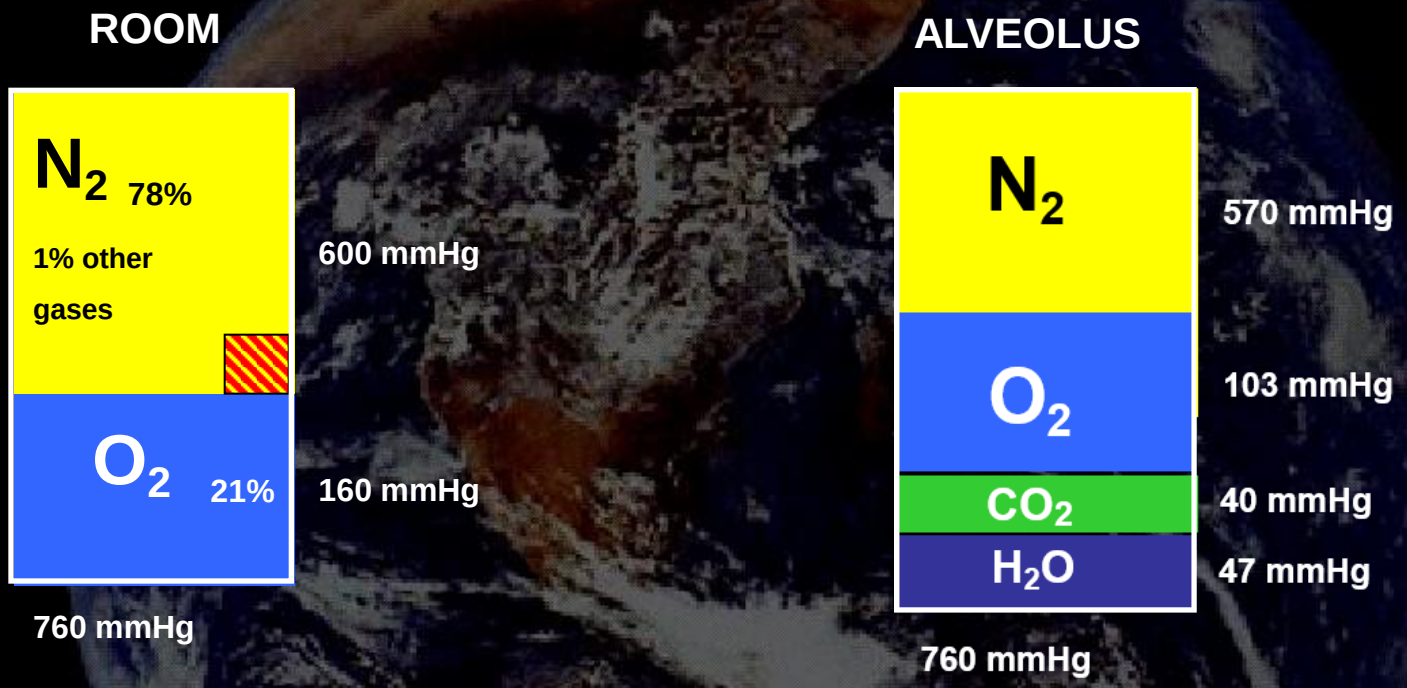
PIO_2	Inspired tracheal oxygen tension
PAO_2	Alveolar oxygen tension
$PACO_2$	Alveolar carbon dioxide tension
$F IO_2$	Fractional concentration of oxygen in inspired (dry) gas
R	Respiratory exchange ratio

Simplified Alveolar Gas Equation (100% Oxygen)

$$PA_{O_2} = \left(PB - P_{H_2O} \right) - PA_{CO_2}$$

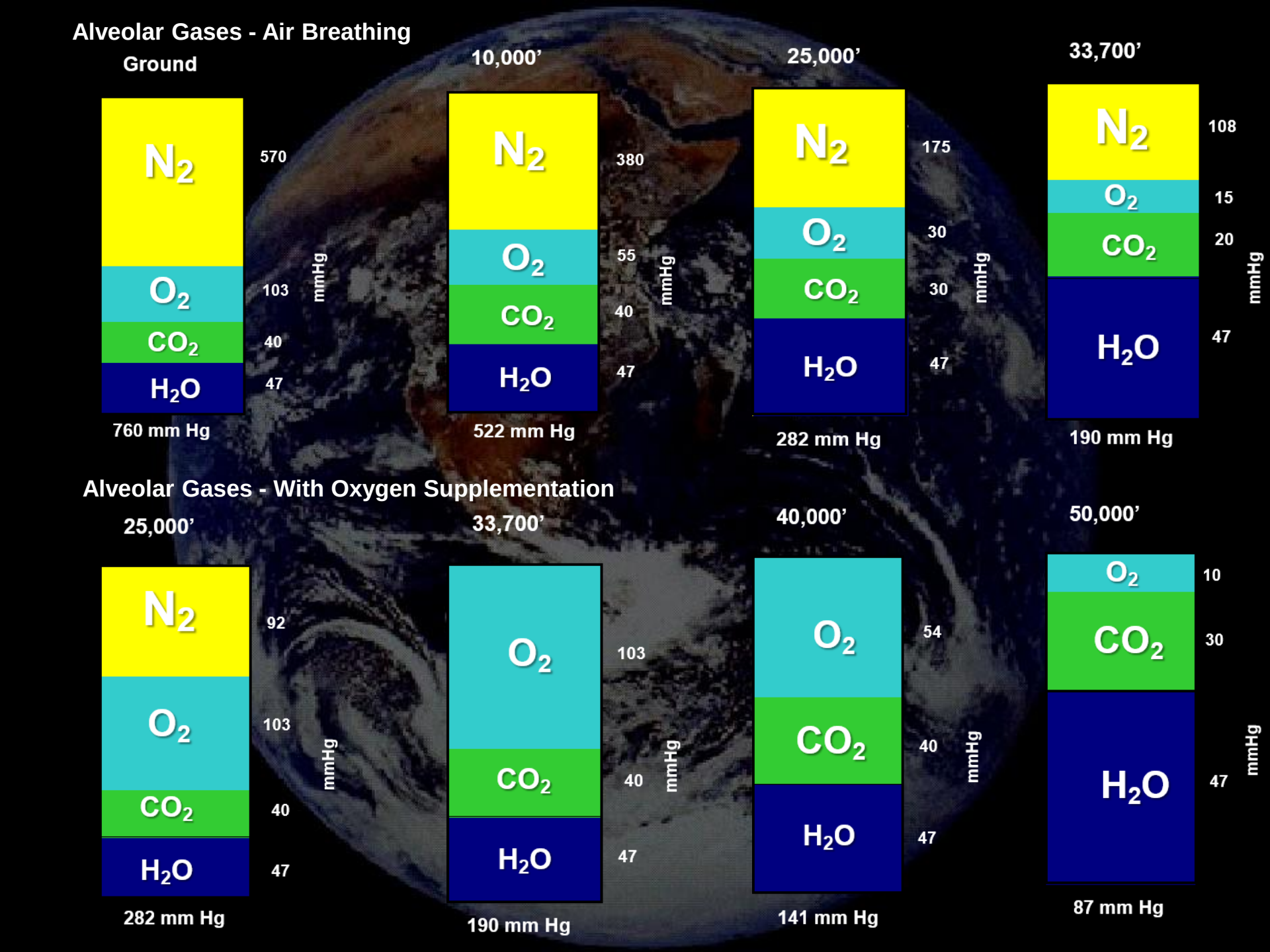
$PA\ O_2$	Alveolar oxygen tension
PB	Environmental Pressure *(Not just Atmospheric Pressure)*
$P\ H_2O$	Water vapour tension at 37°C (47mmHg)
$PA\ CO_2$	Alveolar carbon dioxide tension

Gas Composition at Sea Level



Gas

- Nitrogen N_2
- Oxygen O_2
- Carbon Dioxide CO_2
- Water Vapour H_2O
- Other Gases (Argon)


Alveolar Gases - Air Breathing
Ground
N_2
570
O_2
103
CO_2
40
H_2O
47
mmHg
760 mm Hg
10,000’
N_2
380
O_2
55
CO_2
40
H_2O
47
mmHg
522 mm Hg
25,000’
N_2
175
O_2
30
CO_2
30
H_2O
47
mmHg
282 mm Hg
33,700’
N_2
108
O_2
15
CO_2
20
H_2O
47
mmHg
190 mm Hg
Alveolar Gases - With Oxygen Supplementation
25,000’
N_2
92
O_2
103
CO_2
40
H_2O
47
mmHg
282 mm Hg
33,700’
O_2
103
CO_2
40
H_2O
47
mmHg
190 mm Hg
40,000’
O_2
54
CO_2
40
H_2O
47
mmHg
141 mm Hg
50,000’
O_2
10
CO_2
30
H_2O
47
mmHg
87 mm Hg

Henry's Law
Dissolved Nitrogen

- At ground level, body saturated with nitrogen
- On ascent, fall in *partial pressure* of nitrogen in inspired air means excess nitrogen must leave the body (via lungs)
- Solubility of nitrogen greater in tissues than blood & a backlog develops
- Rate of fall of *absolute pressure* is greater than rate of fall of the partial pressure of nitrogen in tissues (especially following rapid ascent)
- Tissues become supersaturated with nitrogen promoting evolution of gas bubbles in-situ

Henry's Law
Dissolved Nitrogen

Danger of decompression sickness (The Bends)
Possible from 18,000 Feet – ½ Atmosphere upwards

Significant danger with increasing altitude

- Beware of Divers who fly after a dive!

- Divers should not fly for 12 hours after single dive
  18 hours after multiple dives

- Ditto post Hyperbaric chamber operations

Sea Harrier

- High level performance check
- Canopy exploded at 42,000ft (+ aerodynamic suck)
- Emergency descent
- MDC flapping in the breeze
- Gale force wind & cold
- Leveled out at 3,000ft
- Carrier Deck Landing


Lt Cdr Martin (Jack) London 1959-2002

Effects of Hypoxia
Between 15,000ft & 20,000ft Breathing Air

- Symptoms at rest
- Performance of simple tasks impaired & thinking slowed
- Personality changes, loss of self-criticism, insight & will power
- Euphoria
- Muscular & mental in-coordination
- Light-headedness
- Tingling lips & limbs
- Cyanosis
- Darkening of vision
- Amnesia
- Unconsciousness

Times of Useful Consciousness

Altitude	Active	At Rest
18,000ft	20 min	30 min
25,000ft	2 min	3 min
30,000ft	20 sec	30 sec
45,000ft	12 sec	12 sec
50,000ft	12 sec	12 sec
Space	12 sec	12 sec

In space no one can hear you boil

Effects of High Altitude (25,000 feet)

Aloha Airlines Flight 243 April 1988

Explosive Decompression at 24,000 Feet (- 30^0 c) Only 1 Fatality!

Metal fatigue caused by corrosion from operating in an Oceanic environment


BRITISH AIRWAYS

Airbus A380
575 passengers Three Class configuration, 853 passengers Single Class
Cabin Altitude ~ 8000 feet Very Dry Atmosphere
Restricted Movement especially in Economy Class
Longest Flight: Auckland NZ – Dubai 17 Hours 15 Minutes

Fit to Fly

CHRONIC CONDITIONS

Anything compromising good Gas Exchange is a concern:

Stable asthmatics should present no problems but should fly with full medication

Consider prescribing oral steroids for them to start if their condition deteriorates

COPD may need oxygen supplementation in-flight even if the person does not use oxygen at home

Patients breathless at rest should not fly without supplementary oxygen

Airlines have widely different rules regarding the provision of Oxygen and *do not* permit patients own Oxygen to be carried

Bottled Oxygen can be very expensive and may require many bottles

Fit to Fly

CHRONIC CONDITIONS

Oxygen concentrators can be provided/hired and *may* be sufficient

Airlines require 48 - 72 Hours notice and require a doctors certificate pertaining to the actual medical condition requiring oxygen and the dose rate and duration

Not all Airlines will accept a patient who requires on board Oxygen

The actual Oxygen requirement should be calculated well in advance

A simple fitness-to-fly test is the ability of a patient to walk 50 metres unaided at a normal pace, or to ascend one flight of stairs, without becoming severely dyspnoeic – Good enough for short haul

Consider a Hypoxic Challenge Test (HCT)

Fit to Fly

CHRONIC CONDITIONS

The Hypoxic Challenge Test (HCT) reliably predicts patients requiring in flight Oxygen:

Subjects breath a hypoxic gas mixture 15% oxygen in nitrogen (20mins)

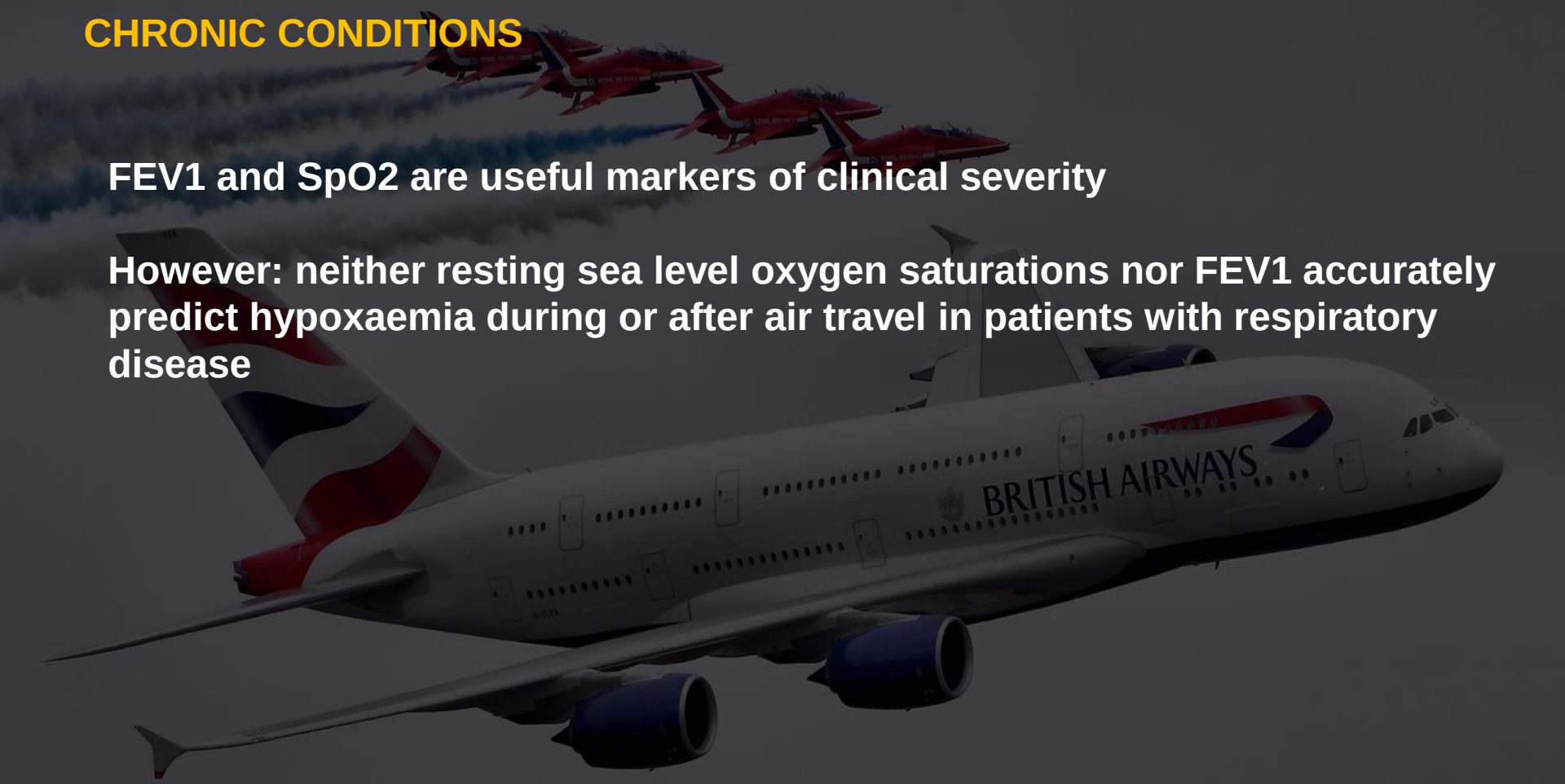
Saturation is monitored throughout and arterial blood gases/SpO_2 are measured beforehand and on completion

PaO2 <6.6 kPa (<50 mm Hg) or SpO2 <85% Requires In-flight oxygen at 2 l/min via nasal cannulae

Air travel is contraindicated if the usual oxygen requirement at sea level exceeds a flow rate of 4 l/min

Fit to Fly

CHRONIC CONDITIONS



FEV1 and SpO2 are useful markers of clinical severity

However: neither resting sea level oxygen saturations nor FEV1 accurately predict hypoxaemia during or after air travel in patients with respiratory disease

Fit to Fly

CHRONIC CONDITIONS

BEWARE of patients with:

Previous air travel intolerance with significant respiratory symptoms, chest pain, confusion or syncope

Severe COPD (FEV1 <30% predicted) or asthma

Bullous lung disease

Severe (VC <1 litre) restrictive disease, including chest wall and respiratory muscle disease especially with hypoxaemia and/or hypercapnia

Cystic fibrosis

Comorbidity with conditions worsened by hypoxaemia (cerebrovascular disease, cardiac disease or pulmonary hypertension)

Within 6 weeks of hospital discharge for acute respiratory illness

Fit to Fly

CHRONIC CONDITIONS

CANCER

Anaemia and Biochemical anomalies should be treated before flight

Pleural Effusions should be drained

Patients should know that medical insurance is likely to be refused if cerebral metastases are present and that repatriation costs are significant

Airlines do not allow patients to fly within *24 h* of a seizure


BRITISH AIRWAYS

Fit to Fly

ACUTE CONDITIONS

Absolute contra-indications to air travel:

Untreated pneumothorax
(But can usually fly *two weeks* after demonstrable effective treatment)

Infectious Tuberculosis

Haemoptysis

Fit to Fly

ACUTE CONDITIONS (Cardiac)

Note that at 8000 ft there is a 5% fall in ischaemic threshold as seen on ECG

Patients who have undergone elective percutaneous coronary intervention (PCI) can fly after *2 days*

Patients at low risk after ST elevation myocardial infarction (STEMI)
namely, restored TIMI grade 3 flow on angiography, age <60, no signs of heart failure normal ejection fraction and no arrhythmias can fly after *3 days*

Other patients may travel *10 days* after STEMI unless awaiting further investigation or treatment such as revascularisation/device implantation

Patients with non-ST elevation myocardial infarction (NSTEMI) should undergo angiography and revascularisation before considering air travel

Patients who have undergone uncomplicated coronary artery bypass grafting should be able to fly within *14 days* (must have a chest x-ray to exclude pneumothorax)

Fit to Fly

ACUTE CONDITIONS (Cardiac)

Rhythm disturbance, pacemakers and defibrillators:

Pacemakers and defibrillators are compatible with aircraft systems

Patients with unstable arrhythmias should not fly

Patients with high-grade Premature Ventricular Contractions should be discouraged from flying

Fit to Fly

Virchow's Triad

Blood Flow Obstruction/Stasis

Atrial Fibrillation
Left Ventricular Dysfunction
Paralysis
Immobility (strapped in a tight seat)
Venous Insufficiency & Varicose Veins
Tumour Obstruction
Pregnancy
Obesity
Plaster of Paris

Endothelial Injury

Trauma/Surgery
Venepuncture
Chemical Irritation
Heart Valve Disease/Surgery
Indwelling Catheters
Atherosclerosis

Hypercoagulability

Malignancy
Pregnancy
Oestrogen therapy
Trauma/Surgery
Sepsis
Thrombophilia

Fit to Fly

Virchow's Triad

Minimise the risk:

The risk of Venous Thromboembolism is greatest on flights lasting >4 h or Multiple short flights (Risk doubles and increases with duration of flight)

Risk is reduced in passengers occupying an aisle seat

Passengers should avoid excess alcohol and maintain good fluid input
Humidification of cabin air is very difficult and cabin air is generally very dry

Passengers should remain mobile and/or exercise their legs during the flight

Low risk patients should be advised to wear below-knee elastic compression stockings

They should be advised against the use of sedatives or sleeping for prolonged periods in abnormal positions

Fit to Fly

Virchow's Triad

Minimise the risk:

There is no evidence to support the use of low- or high-dose aspirin

Patients who have had a VTE should ideally not travel for *4 weeks* or until proximal (above-knee) deep vein thrombosis has been treated and symptoms resolved, with no evidence of pre- or post-exercise desaturation

Pre-flight prophylactic dose of low molecular heparin should be considered or formal anticoagulation to achieve a stable INR of 2 - 3 for both outward and return journeys on a case-by-case basis

Fit to Fly

Post Surgery

Patients should not fly for *10 days* following abdominal surgery

Flying is not advised for *24 hours* after colonoscopy or procedures where a large amount of gas has been introduced into the colon

Flying is not advised for *24 hours* after laparoscopy

Travellers with colostomies need to use a larger bag as intestinal distension during the flight increases faecal output

Air travel should be avoided for seven days following neurosurgery due to the possibility of residual gas being trapped in the skull

Interventions for retinal detachment usually involve the introduction of gas by intra-ocular injections and can cause an increase in intra-ocular pressure
Air travel should not be undertaken for *2-6 weeks* depending on the gas used

Flight should be delayed for *one week* after other ophthalmological procedures or penetrating eye trauma

Fit to Fly

Ears

Middle ear barotrauma results from failure to equilibrate the middle ear and atmospheric pressure difference, and occurs during descent

Children are especially at risk as they have narrower Eustachian tubes

Children are less able to regulate the pressure difference by performing a Valsalva manoeuvre and are more likely to suffer from viral head colds and more likely to have adenoidal tissue obstructing the Eustachian tube orifice

Parents should be advised to encourage their children to drink, chew, suck and blow their nose, particularly during descent to prevent barotrauma

Fit to Fly

Plaster of Paris

Trauma/orthopaedics:

Patients should wait at least *24 hours* following application of a plaster cast for flights of less than two hours

48 hours on longer flights (Air entrapment and tissue swelling with decompression)

Consider bi-valving the plaster cast before flight

Fit to Fly

ENT

Passengers can fly *10-14* days after tonsillectomy or middle ear surgery

If the jaw has been wired for any reason, a passenger may only travel if there is an escort equipped with wire cutters or if a self quick release mechanism is fitted

Fit to Fly

PREGNANCY

Delivery in flight carries significant risks to the mother and baby

Most Airlines refuse to carry women in the latter stages of pregnancy, typically after *36 weeks* for single pregnancies, *32 weeks* for multiple

A certificate is normally required to be carried after *28 weeks* confirming the estimated date of delivery, that there are no complications and, in the view of the doctor or midwife, the passenger is fit to fly

Health travel insurance may be difficult to obtain in late pregnancy

Fit to Fly

PSYCHIATRY

Because of safety implications, **psychiatric disorders** need to be stable and controlled

Acute severe conditions (such as an **acute psychosis**) would need to have an appropriately trained medical escort (RMN) plus suitable sedation which can be administered by the escort

Medical clearance must be sought well in advance of intended travel

Beware of other psychiatric conditions temporarily treated with anxiolytics that may be confused by flight staff as alcohol intoxication

Many airlines offer a Fear of Flying treatment program

Fit to Fly

Is the Pilot Fit to Fly - You! (and others)?

UK Civil Aviation Authority

CAA UK Licenses (National Private Pilots Licence) NPPL

From September 2016 a One Off Self Declaration to age 70 then renewed by Self Declaration every 3 years – Class 1 DVLA

CAA Administered European Licenses (EASA Class One and Two)

EASA Class One – Commercial Pilots - Annual / 6 Monthly
By CAA Senior Authorised Medical Examiner (AME)

EASA Class Two and Light Aircraft Private Pilots License (LAPPL)
Private Pilots
Age specific renewal between 5 and 1 years by CAA Authorised Medical Examiner AME or CAA registered GPSI (LAPPL)

Fit to Fly

Is the Pilot Fit to Fly - You! (and others)?

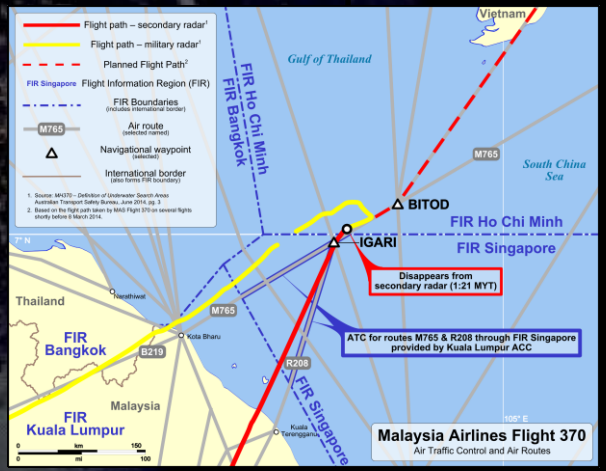
You must inform the UK Civil Aviation Authority if you suspect that a holder of a Pilots License develops an illness associated with lack of insight about their condition, particularly:

Depression, psychosis, alcohol or drug abuse that becomes evident and you believe their decreasing medical fitness renders them unfit to fly

Article 139(2) of the Air Navigation Order 2009 and others

Germanwings Flight 9525

Malaysia Airlines Flight 370



BTS guidelines

https://www.brit-thoracic.org.uk/document-library/clinical-information/air-travel/bts-air-travel-recommendations-2011/

British Airways

https://www.britishairways.com/health/docs/before/airtravel_guide.pdf

Medaire (a private company) provide a 24 hour worldwide cover Doctor to Aircraft advice service

Any Questions?