basildon bsac BRANCH 0356

Boyles Law and its Effects

Boyle's law

Sometimes referred to as the Boyle–Mariotte law states that the absolute pressure and volume of a given mass of confined gas are inversely proportional, if the temperature remains unchanged within a closed system. Thus, it states that the product of pressure and volume is a constant for a given mass of confined gas as long as the temperature is constant. The law was named after chemist and physicist Robert Boyle, who published the original law in 1662.

Rates of Pressure:

Atmospheric Pressure
(BAR) = 1

This always gets added to water pressure when we're talking about "What is absolute pressure at XXX depth?"

Water Pressure
1 BAR every 10.00 meters depth

TIP - To calculate water pressure, just move the depth decimal point 1 place to the left:

- 10 mtrs = 1.0 BAR
- 20 mtrs= 2.0 BAR
- 30 mtrs = 3.0 BAR
- 35 mtrs = 3.5 BAR
- 47 mtrs = 4.7 BAR

To calculate Absolute Pressure

Add the 1 BAR atmospheric pressure to water pressure:

- Absolute pressure at 3 mtrs = 0.3 BAR for water + 1 BAR for atmosphere = 1.3 BAR
- Absolute pressure at 6 mtrs = 0.6 BAR for water + 1 BAR for atmosphere = 1.6 BAR
- Absolute pressure at 27 mtrs = 2.7 BAR for water + 1 BAR for atmosphere = 3.7 BAR

When we say absolute pressure is 3 BAR, it basically means there is three times the normal pressure we'd face standing on land.

Effects When Descending

If we imagine air in a lung, as you descend, the pressure of the surrounding water increases, which means the volume of the lung reduces. Because of Boyle's Law, we know it reduces in proportion to the increased pressure of the water:

- Pressure increases times 2 = volume decrease by half
- Pressure increases by 3 times = volume reduces by third

Calculating Lung Shrink Pressure

To calculate by how much lungs shrinks because of the increased pressure, calculate the absolute pressure, then simply convert to a fraction by putting '1' over the top of the absolute pressure:

- Absolute pressure is 2 BAR, air space shrinks to 1/2 of its original size
- Absolute pressure is 3 BAR, air space shrinks to 1/3 of its original size
- Absolute pressure is 4 BAR, air space shrinks to 1/4 of its original size
- Absolute pressure is 5 BAR, air space shrinks to 1/5 of its original size
- Absolute pressure is 6 BAR, air space shrinks to 1/6 of its original size

Effects When Ascending

Thinking of our lungs again, as you ascend the pressure of the surrounding water decreases and if there was no means for the air to escape, the lung would expand. Because of Boyle's Law, we know it will expand in proportion to the reduction in water pressure:

- Pressure decreases by half = volume increases x 2
- Pressure decreases by third = volume increases x 3

Calculating Lung Expanding Pressure

To calculate by how much lungs expand by the time you reach sea level because of decreasing pressure, calculate the absolute pressure, then simply multiply by that figure:

- Absolute pressure is 2 BAR, lungs expand to 2 times normal size
- Absolute pressure is 3 BAR, lungs expand to 3 times normal size
- Absolute pressure is 4 BAR, lungs expand to 4 times normal size
- Absolute pressure is 5 BAR, lungs expand to 5 times normal size

Fortunately for us, our SCUBA gear delivers air to us at the same pressure as the surrounding water is exerting on us – that way our lungs don't shrink as we descend. In other words, surrounding pressure is trying to shrink our lungs so we need to have air that is 'strong' enough to push back and counteract it. So to make that air in our lungs tough enough for the job, it needs to be stronger i.e. of greater pressure than normal.

The same ratios apply for increased amounts of air at depth as for lung expansion on ascending amount of air:

- Absolute pressure is 2 BAR, we need 2 times normal amount of air
- Absolute pressure is 3 BAR, we need 3 times normal amount of air
- Absolute pressure is 4 BAR, we need 4 times normal amount of air
- Absolute pressure is 5 BAR, we need 5 times normal amount of air

So never hold your breath or you will go bang!

Formulas To Remember:

- **Breathing Rate at Depth** = Rate Per Minute At Surface x Absolute Pressure at Dive Depth

Most preferable is to use your own breathing rate. Exams will give you a breathing rate in litres per minute (usually based on surface). To calculate breathing rate for any given depth, multiply the rate per minute at the surface by absolute pressure i.e. breathing rate of 25 ltrs per min at the surface would increase to 100 ltrs per minute at 30mtrs (Absolute pressure at 30mtrs is 4 BAR – see above)

- **Volume of Gas in a Cylinder =** Cylinder Capacity x BAR Pressure of Gas

  - A 10ltr cylinder pumped to 220 BAR holds 2200 ltrs of gas (10 x 220)
  - A 15ltr cylinder with 150 BAR holds 800ltrs of gas (15 x 150)

- **Rate of Gas Consumption** = Litres of Gas / Breathing Rate Per Minute

Assumed breathing rate at surface of 20 ltrs per min. Using the 15ltr cylinder above with 800ltrs of gas, at the surface it would last 40 mins (800/20). However, at a depth of 30mtrs (absolute pressure = 4 BAR resulting in breathing rate of 80 ltrs per min), gas would only last 10 mins (breathing rate = 4 x 20 = 80 ltrs per min. So 800 / 80 = 10)

- **Gas Reserve** = Target Volume of Gas At Surface (one third of total starting volume)

12ltr cylinder with 200 BAR of gas has volume of 2400 ltrs (12 x 200). Aim is to surface with one third of this volume i.e. either 800 ltrs (2400 /3) or 67 BAR (200 / 3)

  - TIP - In exams this reserve usually needs to be added into gas calculations as a matter of course. The question will rarely remind you to do it!

For Example- How much gas is required to dive for 30mins at 20 mtrs with surface breathing rate of 25 ltrs per min?

- Absolute Pressure @ 20mtrs = 3
- Breathing Rate @ 20mtrs = Rate at Surface x Absolute Pressure = 25 x 3 = 75 ltrs per min
- Amount of Gas required = Breathing Rate per min x Number of Mins = 30 x 75 = 2250ltrs

BUT THAT IS GAS JUST FOR DIVE – RESERVE OF 1/3 REQUIRED TO BE ADDED:
Either divide total gas by 2 then multiply result by 3 i.e. (2250/2)x3 OR Multiply total gas by 1.5

- In our example, total gas required for dive is either:
- 2250 / 2 = 1125, then x 3 = 3375 OR 2250 x 1.5 = 3375
- So answer to the question would be 3375 ltrs required.

What Size Cylinder Required?

- If a range of cylinders with BAR pressure quoted, simply calculate volume of gas in each to determine which you need (remember - cylinder capacity x BAR pressure of gas):

  - 220 BAR pressure in 10ltr, 12ltr & 15ltr cylinders results in
  - 2200 = 10ltr, 2640 = 12ltr and 3300 in 15ltr.

- Hence in our example above, the dive could not be carried out – it would need to be shorter, shallower or both OR the BAR pressure in the cylinder would need to be increased by 5 BAR to produce an additional 75 litres i.e. Gas Needed / Cylinder Capacity = 75 / 15 = 5 BAR.

- If given cylinder size and asked what BAR pressure of gas required, divide total volume of gas by cylinder size:

  - A 10ltr cylinder pumped to 220 BAR holds 2200 ltrs of gas (10 x 220)
  - A 15ltr cylinder with 150 BAR holds 800ltrs of gas (15 x 150)

- If given BAR pressure and asked for minimum cylinder size, calculate total gas required (including one third reserve) and divide by BAR pressure of gas:

  - Using our example, we know we need 3375ltrs of gas.
  - If told we have 230 BAR pressure, what size cylinder do we need?
  - Total Gas / BAR Pressure = 3375 / 230 = 14.67 (or 15ltr cylinder)

TIP - Remember maximum test pressure of cylinder normally 232 BAR so if asked if possible to do our dive on ANY other cylinder size, answer is no as BAR pressure required would be higher than test pressure rendering it unsafe!