PHYSICS

Light:

The speed of light changes as it passes through different things such as air, glass and water. This affects the way we see things underwater with a diving mask.
As the light passes through the glass of the mask and the air space, the difference in speed causes the light rays to bend; this is called *refraction.* To the diver wearing a normal diving mask, objects appear to be larger and closer than they actually are - about 33% larger and closer by a ratio of 3:2. (If the object is actually 3m away it will appear only 2m away when viewed through a diving mask and 33% bigger).

Turbidity (Bad visibility underwater) can cause the diver to perceive (think) that objects are further away than they actually are because they obscured by particles in the water. This phenomenon is known as *visual reversal.*

As light hits the surface of the water the light waves are scattered in all directions this is why we get less light as we go deeper. The better the clarity of the water and the higher the angle of the sun the more light penetrates

Light is also *absorbed* as it travels through water; the longer wavelengths disappear first, which in the spectrum is red. So the *red* colours are the first to disappear and blue last.

Sound:

Sound travels *four times faster* in water than it does in air. This is because the water is a *denser* and more elastic medium than air - 800 times more dense. Because of this the diver's brain perceives the sound as reaching both ears at the same time. This means he cannot tell the *direction* the sound is coming from. The sound seems to come from everywhere at once or *overhead*. Although the diver cannot tell the direction he can tell whether the sound is either closer or further away depending on its volume. Sound can travel very long distances underwater.

Heat:

Water has a much higher *heat capacity* than air; this is its ability to draw heat away from another object such as a diver. Water conducts heat away from the diver *twenty times faster* than air for a given temperature. This is why a diver will chill quickly without an exposure suit even in warmer water.

The diver loses heat by three different methods while underwater.
The first method is *conduction* which has the *most effect* on the diver. This is caused by the water drawing heat by direct contact with the diver or his suit.
The second method is *convection*; this is caused by the movement of the water around the diver.
The third method is *radiation* which has the *least effect* on the diver; this is caused by the diver radiating his body heat out to the water.

Pressure:

Pressure is measured in bar or atmospheres (atm), which are essentially the same.

Gauge pressure is the pressure of the water at a given depth.

Absolute or Ambient pressure is the water pressure plus the atmospheric pressure. (At sea level the atmospheric pressure is 1 bar/atm).

Pressure increases in sea water by 1 bar every 10 metres.

Pressure increases in fresh water by 1 bar every 10.3 metres.

To calculate gauge pressure in bar, simply multiply the depth of the water by 0.1 for seawater and by 0.097 for fresh water.

Examples:

To calculate the gauge pressure at 37m in sea water.

37 x 0.1 = 3.7 bar.

To calculate the gauge pressure at 16m in fresh water.

16 x 0.097 = 1.55 bar.

To calculate the absolute/ambient pressure in bar simply repeat the above procedure and then add 1 (providing you are calculating for sea level).

Examples:

To calculate the absolute pressure at 27m in sea water.

27 x 0.1 = 2.7
2.7 + 1 = 3.7 bar.

To calculate the absolute pressure at 22m in fresh water.

22 x 0.097 = 2.14
2.14 + 1 = 3.14 bar.

To calculate the ambient pressure at 40m in fresh water at an altitude where the atmospheric pressure is 0.7 bar.

40 x 0.097 = 3.88
3.88 + 0.7 = 4.58 bar.

Remember that in all questions in physics of diving (except if they just ask you for the gauge pressure) you will use absolute pressure in your calculations.

Pressure and volume:

For all intents and purposes you cannot compress a liquid or a solid by applying greater pressure, but you can compress a gas as the molecules are further apart. Boyle's Law states that the volume of a gas is inversely proportional the surrounding pressure on the gas.

So it looks like this…. Volume = $\frac{1}{\text{Absolute Pressure}}$

Examples:

If you take an inverted bucket down to 20m what would the volume of the air be inside it?

Volume = $\frac{1}{3}$

If a balloon contains 15 litres of air at the surface; what would its volume be if taken down to 40m?

15 ÷ 5 = 3 litres.

If a balloon contains 7 litres of air at 30m and is then taken to the surface; what would its volume then be?

7 x 4 = 28 litres.

Remember, with volume, multiply by the absolute pressure if you go up and divide by the absolute pressure if you go down. Ask yourself a question – 'will the balloon get bigger or smaller ?'. Then you will know whether to multiply or divide.

If you move from one depth to another, it's easiest to take it first to the surface and then back down to the new depth.

Example:

You take a balloon containing 5 litres of air from 35m up to 15m *in salt water*, what would its new volume be?

5 x 4.5 = 22.5 litres at the surface, then take it back down to 15m

22.5 ÷ 2.5 = 9 litres at 15m.

And the same problem *in fresh water*:

5 x 4.395 = 21.975 litres at the surface.

21.975 ÷ 2.455 = 8.95 litres at 15m

A balloon is sometimes referred to a *flexible container*. A scuba tank is referred to as an *inflexible container* – **a scuba tank does not change volume or the amount of air it holds when changing depth.**

Pressure and Density

Now it's all the other way around because as you squash the gas and make its volume smaller you increase its density – if the gas expands (when going up) then you decrease its density. What does this mean?
When calculating densities you divide when you go up and multiply when you go down. The opposite of calculating volumes. This comes into effect when calculating air consumption.

Examples:

A diver breathes 20 litres a minute at the surface; how much air would he breathe per minute at 30m?

20 x 4 = 80 l/min

Look at the following question, this stumped many people on an instructor exam.

A diver breathes 70 bar of air in 10 minutes at 30m, he then ascends to 20m for 20 minutes, how much air will he consume at his new depth?

Okay, the question is in bar as he is using the same tank (this is not a tec question), so we can calculate it in bar.

So first how many bar does he breath in one minute?

70 ÷ 10 = 7 bar/min at 30m

Now take it to the surface

7 ÷ 4 = 1.75 bar/min at the surface. Now take this back down to 20m.
1.75 x 3 = 5.25 bar/min at 20m. He stays there for 20 minutes so:
5.25 x 20 = 105 bar

Just break the question down into small steps and it is easy!

Partial Pressures

Dalton's Law states that in a mixture of gases that each gas exerts a pressure proportional to the percentage of that gas in the mixture.

Air is a mixture of gases, for calculating purposes, 21% Oxygen and 79% Nitrogen. This obviously changes when using mixed gases, such as enriched air/nitrox.

At the surface the pressure is 1 bar, air is made up of 21% oxygen and 79% nitrogen. So the oxygen is responsible for 0.21 bar and the nitrogen responsible for 0.79 bar. As we go deeper the partial pressure of the gases increases in proportion to the overall pressure but the *percentage remains the same*.

To calculate the partial pressure of a gas at depth divide the percentage of the gas in the mix by 100 and simply multiply by the absolute pressure at that depth.

Examples:

What is the partial pressure of oxygen in air at 30m?

21 ÷ 100 = 0.21
0.21 x 4 = 0.84 bar.

What is the partial pressure of nitrogen at 25m with EANx32?
(EANx32 has 32% Oxygen therefore 68% Nitrogen)

68 ÷ 100 = 0.68
0.68 x 3.5 = 2.38 bar.

Another type question related to partial pressures and contaminated air is this:

If a diver breathes air containing 0.5% carbon monoxide (CO) at 30m it would be the same as breathing______ % carbon monoxide at the surface. In this case you multiply the equation out:

Simply 0.5% x 4 bar = 2.0%

This is correct but what you are actually doing is as follows:

0.5 ÷ 100 = 0.005 partial pressure of CO at the surface (ppCO)
0.005 x 4 = 0.02 partial pressure of CO at 30m
0.02 x 100 = 2% convert back to percent. Giving you what this partial pressure would be expressed as a percentage at the surface.

But if the question asks how many percent CO the diver breathes at 30m the answer would be 0.5% the same as the surface. *Read the question!*

One question that stumped candidates recently on partial pressure when like this:

What would be the approximate partial pressure of nitrogen in air if breathed at altitude where the ambient pressure was 0.7 atm ?

79 ÷ 100 = 0.79 x 0.7 (the absolute pressure in this case) = 0.556 bar
The actual answer was 0.56 but it was multiple choice so this would be the nearest answer. Because the question asked approximately they had assumed 80% Nitrogen in the air so 0.8 x 0.7 = 0.56.

Pressure and Absorption of Gases

Although this could be a complex subject being the mechanism behind DCS, dive table and computer algorithms; for PADI exams it is only the simple basics of Henry's Law you need to know.
If the pressure of a gas in contact with a liquid is increased the gas will dissolve into the liquid until a state of equilibrium is reached. *(Saturation).*
If the pressure of a gas in contact with a liquid is decreased the gas will come out of the liquid *(supersaturation)* if this happens quickly bubbles will form in the liquid.

Remember the opened shaken carbonated drink can. Think in diving terms – the liquid is the blood, the gas is nitrogen and increasing/decreasing pressure is linked to changing depth.

Pressure, Temperature & Volume relationships

This is Charles's Law but we'll go into that in a minute if you are interested; for PADI exams it's kept simple
.
So first let's look at temperature and pressure, this would apply to an inflexible container such as a scuba tank.

For every degree Celsius change the pressure changes by 0.6 bar.

If the temperature increases, the pressure increases.
If the temperature decreases, the pressure decreases.

<u>Examples:</u>

A scuba tank is filled to 200 bar at 15 degrees Celsius, it is then left in the sun at a temperature of 30 degrees Celsius – what would the pressure in the tank now be?

30 – 15 = 15 degrees change
15 x 0.6 = 9 bar change upwards
New pressure = 209 bar.

Or a scuba tank is filled to 210 bar at a temperature of 35 degrees C and is then taken into water of 5 degrees C what would the pressure in the tank now be?

35 – 5 = 30
30 x 0.6 = 18
210 – 18 = 192 bar.

Now let's look at temperature and volume this applies to flexible containers or balloons in the questions as in this case the pressure remains the same and the volume changes.

<u>*For PADI exams you don't need to know by how much, just whether pressure increases or decreases in an inflexible container such as a tank. For a flexible*</u>

<u>container, such as a balloon, you just need to know that volume will decrease in colder conditions, and it will increase in a warmer.</u>

Buoyancy:

Archimedes' Principle states: "Any object immersed in a fluid is buoyed up by a force equal to the weight of fluid displaced by the object".

OK let me translate that into diving the fluid is going to be water, either fresh or salt (seawater), and the object will be a diver or something that the diver wants to lift with a liftbag or sink with weights. To do this we usually want to make the object neutrally buoyant (so the object being lifted doesn't shoot to the surface or the diver doesn't sink uncontrollably).

There is a really cool formula to calculate this:

$$\frac{\text{Object weight (in kgs)}}{\text{Weight of 1lt of water}} - \text{Displacement (in litres of water)} = \text{lift (in litres of air)}$$

This is simple in fresh water as one litre of fresh water weighs 1kg

<u>Example:</u>

How much air do you need to add to a lifting bag to make an anchor weighing 75 kgs and displacing 15 litres of water neutrally buoyant ? It is lying in 14m of fresh water.

75 – 15 = 60 litres

But what if the question said it was in seawater?

One litre of seawater weighs 1.03 kilograms, so the equation now looks like this:

(75 ÷ 1.03) -15 = lift
72.82 -15 = 57.82 litres

Some new questions have come up in the Divemaster exams which caused some confusion at first – divers told me that the formula didn't work. Of course it does! Remember you can't mix apples and oranges, or litres and kilos.
Example: How much lead would you need to add to an object that weighs 90 kgs and displaces 100 litres to make the object neutrally buoyant in seawater.

(90÷1.03) = 87.4 - 100 = -12.6 this is a negative amount of litres of seawater you need to displace, how much does 12.6 litres of seawater weigh in kilos?
Easy 12.6 x 1.03 = 12.98 kgs.
So if this was a diver you would have to stick 13kgs on his weightbelt.

If an object is neutrally buoyant in salt water it will sink in fresh water.
If an object is neutrally buoyant in fresh water it will float in salt water.

If an object is positively or negatively buoyant in either fresh or salt water, you cannot determine exactly what will happen when placed from fresh to salt or vice versa unless you know exactly how much positive or negative buoyancy the object has.