NEWSLETTER
ONTARIO ASSOCIATION OF PHYSICS TEACHERS
(An Affiliate of the American Association of Physics Teachers)
January, 2005

The Physics of Scuba Diving

By: Roland W. Meisel

A note about units: in North America, British units are used in scuba diving. In this essay, I will use PSI for pressure and feet for depth, in accordance with common practice. However, I will include equivalent SI or other units where appropriate.

Introduction

There are many applications of physics in sport diving. Divers need to understand these to dive safely, and avoid adding themselves to the accident statistics. During diver training, these physical principles are introduced as needed. In this essay, I have arranged them in a sequence more familiar to the physics teacher.

Pressure

Boyle's Law ($P_1V_1 = P_2V_2$) has a prominent position in scuba diving. In order to carry enough air for a reasonable dive time, the air must be compressed. The pressure inside a scuba tank is about 3300 PSI, which is 225 atmospheres (atm) or nearly 23 000 kPa. This allows 80 cubic feet (2820 litres) of air to be compressed into the tank. If this air is breathed at the surface, i.e. at a pressure of 1 atm, it will last about 140 minutes.

However, pressure increases by 1 atm for every 33 feet (10 m) of depth. At 33 ft, twice as many air molecules are being taken into your lungs as at the surface. As a result, the air will only last about 70 minutes. By the time you reach 130' (40 m), which is considered the limit for sport diving, you will be breathing air at 5 atm, emptying your tank in 28 minutes. The air is also 5 times the density at the surface, and takes on a distinctly syrupy nature as you try to inhale.

As you descend, the pressure of the water around you is rising. To prevent your lungs from collapsing, you must breathe air at the same pressure. Since the air you breathe under the surface is at higher than atmospheric pressure, you must be careful not to hold your breath while ascending. If you try to ascend without exhaling, the alveoli in your lungs will burst, known as an "air embolism". A change in depth of as little as a metre can make this happen. Never hold your breath while breathing compressed air. Some instructors advise "humming" during an ascent, especially an emergency ascent, to prevent damaging your lungs. This rule does not apply to free diving, when you take a breath at the surface, and then hold it while under water, since you are not breathing compressed air.

If you try to breathe air directly from the tank, the high pressure in the tank will easily explode your lungs. The pressure is reduced in two stages. The first stage, attached to the top of the tank, reduces pressure from 3300 PSI to 120-140 PSI. The second stage, in the diver's mouth, is known as the regulator, and contains a demand valve. A slight aspiratory pressure opens this valve, releasing air at 44 PSI to your lungs. Exhaling closes the valve, sending exhaled air out holes in the sides of regulator.

Oddly enough, even a breath of air at 1 atm contains enough oxygen for several minutes. One would think that humans should need to breathe far less often than we do. However, the urge to breathe is not controlled by the level of oxygen in the body, but by the level of carbon dioxide. Holding your breath for as little as 15 seconds causes enough escalation in the level of carbon dioxide to trigger the urge to breath.

Archimedes' Principle and Buoyancy

An object immersed in a liquid feels a buoyant force equal to the weight of water displaced. If the buoyant force exceeds the weight of the body, it floats. A diver in a wet suit usually floats. It is necessary to wear lead weights in order to descend easily. More weight is required when diving in salt water compared to fresh water.

As the diver descends, the air bubbles in the wet suit are compressed, decreasing buoyancy. To compensate for differing buoyancy at different depths, divers wear "buoyancy compensators", or BCs. The BC is connected to the air tank. Air can be let in to increase buoyancy, or let out to decrease buoyancy. Usually, the diver experiments to determine the minimum amount of weight needed to begin the descent.

Heat Transfer

Water removes heat from the human body much more efficiently than air does, since it has 3200 times the specific heat capacity of air. A diver must wear protection while diving, even though the same temperature in air would feel comfortable.

Light Absorption

Light is absorbed as it passes through water. Different colours are absorbed at different rates, with red being absorbed the most, and violet the least. As a diver descends, the world gets darker and bluer, as all of the colours other than blue and violet are absorbed. Taking photographs below 10 m requires a strobe, or flash, both for illumination, and to "replace" the missing colours. Otherwise, all photos come out in shades of blue and violet, with very little of the other colours.

Magnification

Since water has a refractive index of 1.33, compared to 1.00 for air, objects seen through a diver's mask appear magnified by the ratio 1.33:1.00, or 4:3 using integers. Sharks, for example, look bigger than they really are.

Sound

Sound travels about 4 times faster in water than in air. This can lead to errors in estimating the direction of a sound. Most sounds reach each the ear at a slightly different time. The brain uses this difference in time as one of the clues in determining the direction that the sound came from. However, this time is shortened by a factor of four in water, leading to errors in interpretation. To a diver, a sound can often seem to be coming from all directions at once.

If you try to talk under water, the sound from your vocal chords is not transmitted efficiently from the air in your mouth to the water. Hence, talking under water doesn't work well. There are some devices available that attach to a regulator, permitting talk under water.

Gases in Solution

Henry's Law states that the amount of a gas that will dissolve in a liquid is directly proportional to the partial pressure of the gas. As a diver descends, the partial pressures of the gases in the lungs increase, resulting in a larger amount of these gases dissolving in the blood and tissues of the body.

Oxygen Toxicity

Compressed air is 21% oxygen, and 78% nitrogen, with traces of other gases. At 1 atm, the partial pressure of oxygen is 0.21 atm. However, as pressure increases with depth, the partial pressure of oxygen increases in direct proportion. If the partial pressure of oxygen exceeds 1.4 atm, enough dissolves in the blood and tissues of the body to have a toxic effect on the brain. At normal limits for sport diving, 40 m, the partial pressure of oxygen is 1.05 atm, below the toxic limit. However, if a diver wants to go much deeper, a different mixture of gases is required. Usually a mixture of oxygen and helium is used for deep dives. The mixture is adjusted to avoid oxygen toxicity for the desired depth limit of the dive. Helium is used as a mixing gas to avoid nitrogen narcosis, explained below.

Nitrogen Narcosis

As a diver descends, the nitrogen in the compressed air also dissolves in the blood and tissues of the body. At depths of 100' or more, this dissolved nitrogen can have a narcotic effect on the diver, known as nitrogen narcosis, or "rapture of the deep". The diver may forget important issues, such as ascending before the air in the tank runs out.

Decompression Sickness

The dissolved nitrogen in the blood and tissues can also lead to decompression sickness. A diver must ascend slowly, to allow some of the dissolved nitrogen to leave the blood and tissues during the ascent. If too much nitrogen has been absorbed, the diver must make decompression stops at one or more stages of the ascent. Tables for sport diving limit the amount of time that a diver spends at any particular depth such that decompression stops are not required. However, most divers will make a safety stop at a depth of 15' (5 m) for several minutes, just to be sure. At the limit for sport diving, 40 m, allowable no-decompression time is only about seven minutes. If a diver ascends too rapidly, or does not make required decompression stops, the nitrogen can come out of solution as bubbles in the blood and tissues. This causes pain, especially in the joints, and is known as decompression sickness, or the "bends". Bubbles move through blood vessels, but usually get stuck when they reach capillaries. If enough bubbles accumulate, the diver may die. Treatment for the bends is either a return to depth (if sufficient air is available), or a quick trip to a decompression chamber, if one is available.

You may wonder why fish don't get the bends. Since they don't breathe air, they do not have nitrogen dissolved in their blood and tissues, making decompression sickness impossible.

At the end of a dive, some residual nitrogen is still dissolved in the blood and tissues. The next dive must take this into account, if it is made before the residual nitrogen leaves the body.

Dive Computers

Since the amount of nitrogen dissolved depends both on depth and the time spent at that depth, common safe practice is to assume that the entire dive was made at the maximum depth reached. You can also purchase an electronic dive computer, which takes into account the differing times spent at differing depths, allowing more time in the water.

Nitrox

A diver may take a special course to learn how to use enriched air, commonly known as Nitrox. The ratio of oxygen to nitrogen is increased, allowing for longer bottom times before reaching no-decompression limits. However, the danger of oxygen toxicity is also increased.

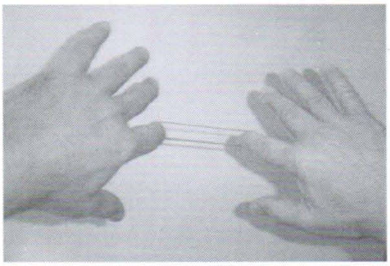
Conclusion

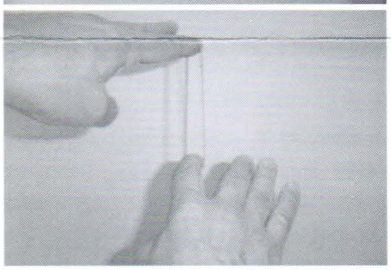
As you can see, there are many physical principles that play a part in sport diving. Diving is not dangerous, but is very unforgiving of any stupidity or neglect. The diver must learn and practice safe procedures to ensure that the sport does not result in injury or death.

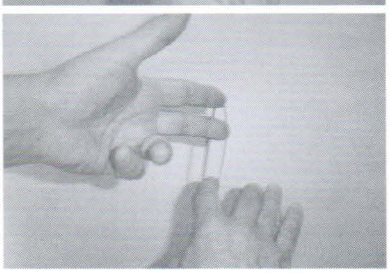
The Demonstration Corner

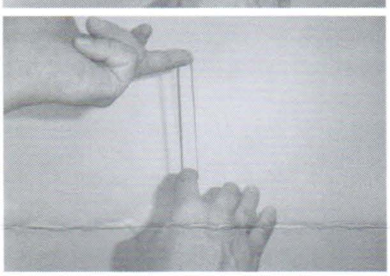
Rotational Motion and the Chain Saw

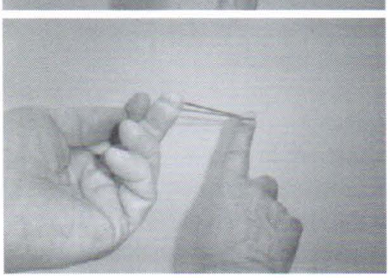
By: John Caranci











This demonstration is used to introduce rotational motion by using the complex motion of a chain-saw chain. You probably have seen many demonstrations over the years but this is one that can be done with the simplest equipment: one elastic band and a sheet of newsprint.

It might be disadvantageous to do this in middle school or junior secondary classes for obvious safety concerns but it can be used at any level with appropriate safety cautions. This is an exciting introduction to complex rotational motion.

The technique is simple, but requires a little practice. The elastic band is held at the tips of the index fingers with palms facing out (first picture). The left hand is rotated 90 degrees counterclockwise (second picture) so that the two index fingers are right above each other, palms facing down. This gives the right strand of the elastic a slight bit more tension than the left strand. The left hand is then rotated 180 degrees counterclockwise, but while the movement is done the second finger of the left hand is placed inside the elastic at about ¼ to ⅓ of the way down the right strand (pictures three and four). The second finger of the left hand is now the active finger and the index finger is relaxed and let go. This produces a right strand that is much tauter than the left one. It is now ready for launching.

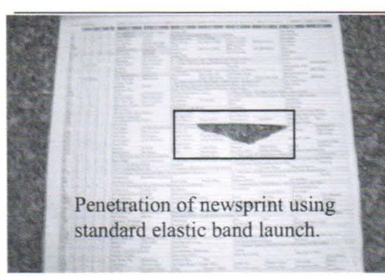
When launched, the elastic forms a flattened ring that moves as a chain saw moves.

The first launch is to compare distance. An elastic band is fired at the back of the class in the normal fashion. Then the band as described above is fired. The results are very different. Try it for accuracy and the results are also very different.

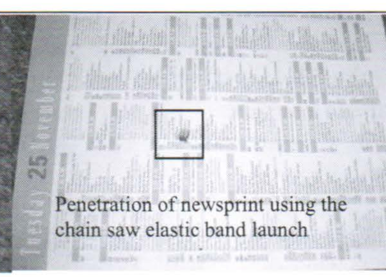
The most telling phenomenon is power to move through a barrier. A piece of newsprint held taut is shown below.

Many senior secondary and first-year students can analyze these phenomena in many ways. Be true to the demonstration and do not give away solutions.

John is a retired Toronto teacher/consultant. He now works for Scientists in School and is the instructor for the OISE Honours Physics AQ Summer Program.



Penetration of newsprint using standard elastic band launch.



Penetration of newsprint using the chain saw elastic band launch

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Submissions describing demonstrations will be gladly received by the column editor.

Let's Play: Quotable Quotes!

Here's the deal. Identify the famous scientist who said the quote below. Be the first person to email your response (c/w mailing address) to the editor, Paul Passafiume, at paulpassafiume@hotmail.com and you'll win a prize! It's that easy. Here we go!

"I think I can safely sat that nobody understands quantum mechanics."

OAPT Conference Reminder!

Just a reminder of this year's OAPT conference hosted by Laurentian University from May 26 – 28, inclusive. This year's conference is sure to be a thrill with such features as the Sudbury Neutrino Observatory (SNO). Be sure to apply for funding from your board, and OSSTF. See you there!

Do you want to give back to your profession? Participate in the OAPT!

This wonderful organization needs volunteer help in the following capacities:

- Guest presenters
- Conference organizers, and facilitators
- Members of the executive committee
- Article, and classroom idea contributors for the Newsletter

New articles, ideas, or other information items may be sent to Glen Wagner (GWAGNER@cwdhs.ugdsb.on.ca) or Paul Passafiume (paulpassafiume@hotmail.com). Ideas for demos may be sent to Ernie McFarland (elm@physics.uoguelph.ca).

Membership Matters!

Join the Ontario Association of Physics Teachers! Members receive a Newsletter and reduced registration rates at the annual conference.

As well, from time to time, the Association makes available special resources. Examples have included reprints of **"Demonstration Corner"** articles from the **Newsletter**, and the videotape, **"The Physics of Dance,"** from a presentation at one of the annual conferences.

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