MS for Tropical Fish monthly

Lights and Lighting by Dr David Ford

Our technical writer looks at aquarium lighting with the usual fundamental scientific information. But this explains why and how we use aquarium lights and offers practical advice too.

Fundamentals

You, your fish and indeed everything else in the Universe is made up of atoms. However, the latest research by 'atom-smashing' machines has shown that these incredibly tiny atoms are made-up of even tinier particles. So far, over 200 different particles have been discovered and indeed these may consist of even smaller things, called 'strings' (or perhaps not - let's hope the Large Hadron Collider at Cern in Switzerland sorts this out!).

The fundamental particles discovered so far, fall into two groups: solid matter particles called Leptons and Quarks and the force particles (four of them) that control them.

Two of these particles are of interest to the aquarist, the matter particle in the Lepton series called the **electron** and the force particle called the **photon**. The electron carries an electric charge and as it flows in the subatomic world the effect we see in our world is called electricity. Hence the electron operates our heaters and thermostats, turns our pumps and powers our lighting.

The photon is a particle (or it can behave as a wave – all very weird) that carries an electromagnetic force that has an effect on those electrons. Photons stream from things around us into our eyes and affect the electrons in the retina, which creates electricity in a 100 billion nerve cells, that flows to our brain and we see 'light'. That same photon-electron reaction energises chemical reactions (called photosynthesis) in plant cells to give growth of the aquatic plants.

The chemicals that carry out the photosynthesis have Copper as one of the atoms involved and this imparts a green colour to the compounds – hence your aquatic plants are mainly green, just like most land plants.

RGB Colours

The photon/electron reaction operates the other way around too. Streams of electrons can strike chemicals that respond by emitting photons. This is called fluorescence (note spelling – even well-known manufacturers print leaflets with the o before the u in 'fluorescent'). A classic example is the original TV sets (before flat screens – these use the same electrons into photons process though) where a stream of electrons (fired from a 'gun'), varying according to the signals (i.e. the programme you are watching). These electrons strike the inside of the screen where three chemicals that fluoresce red, green or blue are made to glow. These are called the primary colours because combinations will give you every colour of the rainbow and equal amounts of each gives white.

The ideal colour TV would have all the rainbow colours – red, orange, yellow, green, blue, indigo and violet - as fluorescing spots in every tiny cell of the screen, but the technicalities and cost make this impractical, so the three primary colour compromise is mass produced.

The same compromise occurs in fluorescent lighting. The ideal would be to flood the aquarium with photons that cover all the rainbow colours, just like the noonday sun that shines over the tropical streams and coral reefs. Cost and complexity means only part of the colour spectrum can be chosen, so manufactures choose a range suitable for plant growth, or algae growth or inhibition, for colour enhancement of the fishes, or brighter or dim displays, even moonlight colours.

The Amazing Photon

The most fantastic property of the photon is that it can behave like a particle (i.e. a discrete lump of matter) or a wave (it radiates in a continuous flow) according to how you observe it. In its wavelike character, the energy the photon possesses is measured by its wavelength and frequency, and it is that energy that determines its colour.

The low energy photons will be red, then, as the energy level increases, i.e. the frequency (or cycles of waves per second) is higher; they are orange, yellow and green to blue. Our sun issues photons in the middle of this range and so is a yellow colour and land plants are 'tuned' to this frequency. When the photons hit water they are slowed down; simply because water is thicker than air. The less energetic photons get absorbed first, so the red ones disappear, then yellow, leaving the blue as the last to go before it gets dark. Hence deep corals live in a blue world and the corals that photosynthesise are tuned to this frequency. Most coral fishes have eyes that see blue, violet, and even ultraviolet (which we cannot).

The shallower freshwater plants of jungle streams use the yellow to blue range of light for photosynthesis. In addition, the number, as well as the energy, of the photons, determines how much photosynthesis takes place. This is the amount of light received i.e. the light intensity.

Photosynthesis

The chemical family that carries out photosynthesis is, of course, chlorophyll, but it comes in two major types called, by botanists, ‘a’ and ‘b’. Chlorophyll-a absorbs photons of wavelength 400 to 450nms (see box for an explanation of nms) which is blue to our eyes. Chlorophyll-b absorbs 500nms which is blue-green to us. Most aquatic plant leaves have both types of chlorophyll at a ratio of 2 parts ‘a’ to 1 part ‘b’ so the plant can use the most effective photons (the blue ones that penetrate the water) but still access the yellow ones (from the yellow sun) that are available at midday when a tropical sun is overhead.

Another feature of the chlorophyll-a type is that it can ‘switch on’ again beyond the green colour into the red range (700nms) so plants can even make use of the setting sun (when it turns red – not the sun, of course, but the rays of light).

Algae photosynthesise but not all use chlorophylls. Many species have a more primitive form of photosynthesising chemicals called carotenoids. A classic example is *Phaeophyta* which always forms first in the new aquarium. Without chlorophyll, the alga is not green and aquarists actually call it ‘brown algae’.

The green algae have some chlorophyll but also still use carotenoids. The carotenoids absorb photons at 500nms down to 400nms; that is blue to violet; hence blue lights encourage algae whereas ‘warm-white’ lights encourage plants rather than algae. This is why marinists who keep living rock will fit blue lights for the algae in the coral heads to photosynthesise, but the same lighting is unsuitable for the Amazonian tank, where higher plants need to outgrow the algae. In Dutch aquaria (open topped tanks with plants growing out of the water) the lighting of choice is dichroic (means cool burning) spot lights, which are as yellow as the sun.

The common fluorescent tube lighting, as used in offices for example, emit photons at the yellow, orange and red end of the spectrum, hence they do allow photosynthesis to occur, but since these photons are the first to be absorbed by the water, the lighting is weaker than it looks in air. This is why special aquatic fluorescent tubes have been developed that emit photons in the bluer end of the spectrum to encourage both chlorophyll-a and chlorophyll-b to work…there are many on the market with names like: Triton, Beauty light, Coralife, Aqua Glo, Sun Glo, Power Glo, Aquastar, and so on.

Light Intensity

The energy content of the photons is important to your choice of lighting for your planted aquarium, but equally important is the number of those photons, i.e. the amount of light. This is called the intensity and is measured in various ways. Because of history it was measured in candles, based on the light from one special wax candle. Modern measurements in the SI system (System International) are still called 'candelas' and is now "1/60th of the light intensity of 1 square centimetre of a perfectly black body at the freezing point of Platinum"!

This is the number of photons emitted, but we need to know how many are received in a given time, which is a different measurement, called Lumens. Also the distance travelled, hence illumination was in foot-candles (where measured in feet). Most manufacturers describe their lamp's output in Lumens e.g. Interpet's Triton is 600 Lumens for the 15 watt, 18" tube and 2000 Lumens for the 40 watt, 48" tube.

The photons that flood from these lights into the tank arrive at the water surface at 300,000 kilometres per second but are then slowed by the water to 225,000 km/s, the shock of which causes the light rays to bend. Glass slows down the photons even more, to 197,000 km/s, so a cover-glass has a dramatic effect too (one reason why Dutch aquariums are open topped). Then the light spreads out and becomes weaker with tank depth.

Starter Units

A simple light bulb was the original lighting that aquarists used but they had major problems – they produce a lot of heat and the lifespan was short. On the other hand the yellow spectrum photons were good for plants and some aquarists still insist on adding a bulb (or two) inside the tank top for better plant growth. These filament bulbs have a Tungsten wire that glows hot from the electrons that race back and forth at 50 cycles a second, hence all that is needed is a mains electricity supply.

The Tungsten bulb is incandescent (heat glow) but a Mercury lamp is fluorescent. The mains supply of electrons acts on the Mercury vapour to force the electrons in the atoms of Mercury into a different orbit and when they drop back from this 'excited state' they give out the energy originally gained as photons. These photons are very energetic and so are coloured blue, indeed they pass into the ultraviolet range. By altering the pressure and chemistry of the Mercury within the bulb (i.e. High Pressure Mercury or Mercury halide) the ultraviolet produced includes visible light and special glass can screen out the potentially harmful ultraviolet. The blue light is very penetrating and mercury lights are popular with marinists who own living rock and coral reef systems in deep aquaria.

If that Mercury vapour is reduced and added to a long tube rather than a bulb (to maximize the surface area) the gas will still produce ultraviolet rays if bombarded with electrons from filaments sited at each end of the tube. The inside surface of the tube is coated with a Phosphorus chemical (called phosphors) which emit photons when bathed in this ultraviolet radiation. This is fluorescence and hence we have a fluorescent tube with the wavelength of the photons determined by the chemistry of the phosphor coating. Each manufacturer has their own secret recipe for the phosphor and offers a range of lighting effects. There are white, warm white, actinic (a blue photon at 420nm, the wavelength used by many Corals). Another chemical used like Mercury is Sodium with its very yellow photons….they can be seen as the fog-piercing street lights all over the UK.

All these lights rely on an arc being struck between electrodes that cause a stream of electrons to pour out. In Mercury bulbs the arc can be seen but in fluorescent tubes they are hidden by the coating. To start the process going the electrodes sited at each end of the tube have to be warmed-up, then a stream of electrons triggers the gas to emit ultraviolet that excites the phosphors into fluorescing. This chain of events begins with the 'starter', the little white plug that slots into the 'starter unit'.

It contains a switch (suppressed to prevent interference with radio or TV) and when the mains electricity is applied, the starter can be seen to glow as the electrons pass through to the cathodes (as they are called) in the tube ends. This glow is actually from a bimetal strip, and, just like the thermostat in the aquarium heater, it heats up and turns itself off, taking no further part in the process (it can even be removed once the tube is on). It will not be needed until the tube is turned off and then back on. If the tube fails to light always check this starter first – it is best to have a spare one standing by – as the starter often fails before the fluorescent tube does.

The cathodes in the tube are heated via the starter and emit a stream of electrons that 'fire' the gas into making the phosphor glow. You can see this happening when the ends of the tube glow, and then the whole tube flickers and floods with light (often you can hear this happening too – the 'clinking' noise).

To maintain the process once it is underway, a higher voltage than the mains supply is needed and the rest of the starter unit has a 'choke' where the voltage is stepped up (unlike the transformer of TV games machines or computers, where the voltage is stepped down). Chokes and transformers are heavy because they contain many yards of Copper wire and magnetic plates. This is why the starter units are so big and heavy.

Once the glowing process is under way, the large number of electrons needed initially is much reduced and since it is the total number of electrons we use that determines the electricity bill, fluorescent tubes are much cheaper to run than filament bulbs for the same amount of lighting. This is also why they are cooler then filament bulbs and so more lights can be fitted into an aquarium hood without heat damaging the top surface.

Incidentally, the electron flow can actually push the phosphor coating along the tube so an ageing light can be seen to have dark rings (absence of a coating) at the ends. The phosphor also breaks down eventually which are why the luminosity reduces with time and makers recommend new tubes after a year or so, even though they seem to be still working. The plants will know that they are not as bright, and suffer accordingly, even though you may not notice the fading.

Developments

Technology marches on: fluorescent lamps are being made in miniature sizes so less power is needed to start them. Other units have the starter and choke built into the ends, reducing the amount of wiring needed. Long-life tubes are being made (e.g. Blue Moon is a tube with guaranteed 5000 hours). Some models no longer fade with age but remain bright until they fail altogether (e.g. Triton where the phosphor is fixed to prevent migration).

Remote and highly efficient 'smart' ballasts are now available for Mercury lamps.

Tubes can have internally reflecting coats to increase light efficiency, or are twisted for increased surface area. The colour of the photons is designed for specific use with makers declaring the actual range produced – this is in temperature terms as degrees Kelvin (K). Read the manufacturers data sheets to see what colour range they offer. For guidance, the tropical sun at midday is 5000K.

The latest additions to the wonderful world of lighting are the LEDs – which stands for Light Emitting Diodes. These are semiconducting electrodes (transistors) which emit photons if excited by the usual electron flow. The technology is different but the principles are the same.

Practical Advice

The subatomic world may be interesting to explain 'why', but the aquarist needs to know 'how' so here is some practical advice on lighting.

- Choose a fluorescent tube that fits easily into the aquarium hood, i.e. 18" for a 2 foot tank, 30" for a 36" tank etc.
- Think where the starter unit can be hidden away since it will make the hood too heavy. I hang them on picture hooks behind the aquarium.
- Note that starter units use electricity too so if calculating the cost of lighting do not just take the wattage of the tube – add 10 watts (so that a 15 watt tube uses nearly 25 watts and a 40 watt tube is really 50 watts).
- Remember that lighting should emulate natural conditions which mean a daily rhythm for the fish and plants – use a timer for 10 to 12 hours on per day starting at the same time every day.
- If pendant lights are used fit them 12" above the water surface to reduce heating effects.
- Read the makers' data so the correct size bulb is used – for example an 80 watt Metal halide bulb is equal to a 150 watt spotlight bulb and a fluorescent tube is approximately twice as bright as a tungsten bulb of the same wattage.
- If banks of lights are used, switch them on in sequence so the fish do not suffer light shock.
- If the evergreen tank (algae) is a problem – try this: use plastic plants (they look so real nowadays) and fluorescent tubes wrapped in red and/or green cellophane (sold by flower shops). These give pleasant light effects in the aquarium (especially with rising bubbles from the aerator) but have wavelengths that are completely wrong for photosynthesis – so no algae!

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Recommended lighting for the average planted community aquarium

Length of tank	Tungsten bulb	Spotlight	Fluorescent	Mercury
18”	1 x 40w	-	1 x 8w (12”)	-
24”	2 x 40w	-	1 x 15w (18”)	-
30”	2 x 60w	-	1 x 20w (24”)	-
36”	3 x 40w	3 x 60w	2 x 25w (30”)	1 x 80w
48”	4 x 60w	4 x 60w	2 x 30w (36”)	1 x 80w
60”	5 x 60w	4 x 100w	2 x 40w (48”)	2 x 80w
72”	6 x 60w	5 x 100w	2 x 50w (60”)	3 x 80w

The fluorescent lights can be combinations of smaller tubes e.g. a 60” tank can have 2 x 40w or 4 x 20w etc.

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Comparisons of lighting type

Type	Advantages	Disadvantages
Natural daylight	No cost, good for plants and triggers breeding	Cannot be controlled and causes algae to grow
Tungsten bulb	Cheap and good for plants	Gets hot and short lifespan
Spotlights	Good water penetration and long life, dichroics are cool	Bulky, needs open top tank
Fluorescents	Cheap to run and easy to install, spectrum can be chosen for type of aquarium	Expensive to buy and replace Bulky starter and wiring
Mercury	Brilliant light Good for deep tanks, ideal spectrum for Corals	Bulky and hot, needs open top Expensive
LEDs	Even more brilliant light Long-lasting (over 5 years)	Bulky and hot, needs air flow cooling Very expensive

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The Nanometre

The nanometre is a measure of the wavelength of the photon and is a billionth of a metre (10^{-9}). The smaller the number the shorter the wavelength and the greater the penetrating power of the photon – this is why the 400nm (blue) photon reaches the deep Corals, whereas the 700nm (red) photon only affects surface plants.

Photon colour	Wavelength	Maximum photosynthesis occurs at
Violet	400-430nm	
Blue	431-480nm	435nm & 445nm
Blue-green	481-490nm	
Green-blue	491-510nm	500nm
Green	511-530nm	
Yellow-green	531-570nm	
Yellow	571-580nm	
Orange	581-600nm	
Orange-red	601-680nm	640nm & 675nm
Red	681-700nm	

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