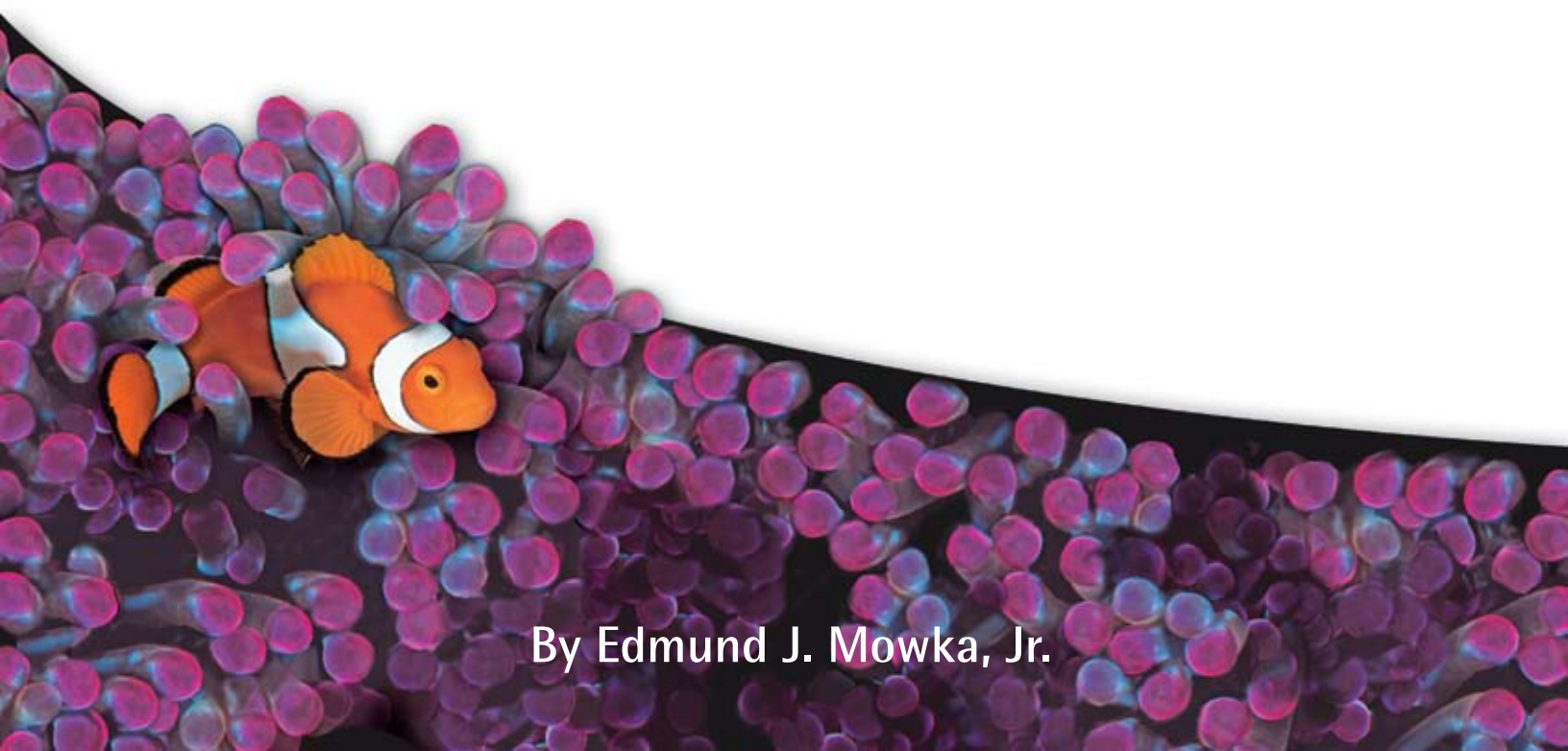




The SeaWater Manual

Fundamentals of Water Chemistry
for Marine Aquarists



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Introduction

A marine aquarium is an unnatural environment. In the sea, water conditions are constant, but in an aquarium, water conditions are continually changing. Since aquatic organisms are in intimate contact with their environment, the changing composition of the water has a profound effect on their well being.

As an aquarist you must be able to recognize the condition of the water in your aquarium, and take appropriate action when water quality declines, as it inevitably will. Acquiring a basic understanding of water chemistry is an important step in becoming a more knowledgeable and, ultimately, a more successful marine aquarist.

It is possible to maintain and enjoy a marine aquarium with little or no concern for routine water analyses. In fact, many hobbyists are content with knowing that regular, partial water changes are sufficient to maintain adequate water quality in many situations. As long as such aquariums are not overcrowded or overfed, there is little reason to expect that water quality will deteriorate enough to be detrimental.

However, many marine enthusiasts are not content with simply maintaining decorative displays. Some are challenged by especially delicate fish and invertebrates. Others are spawning and rearing many popular species.

These aquarists demand to know more about the water in their systems. Analysis of the water can greatly complement the information gained by careful observation of the aquarium inhabitants, and help establish guidelines for future aquarists, both serious and casual.

Seawater is a complex solution, and to accurately determine the concentrations of many components is difficult, time consuming, and costly. Fortunately, experience has shown that we can learn a great deal about aquarium environments by analyzing for a relatively small number of items.

Unfortunately, the marine aquarist wishing to consider water chemistry is often in an uncomfortable position. Bits and pieces of information are frequently gathered from various sources that are contradictory or inadequate.

This booklet attempts to fill the gaps in the aquarist's knowledge of water chemistry. It discusses the nature of seawater, and common water chemistry parameters with emphasis on the type and value of the information that can be obtained from a particular analysis.

To aid in understanding the following chapters, it is appropriate to define several terms before continuing. Additional definitions are also found in the glossary which begins on page 25.



Elements, Molecules, and Ions

The basic chemical unit is the atom. It is composed of three distinct small particles – protons, neutrons, and electrons. The number of protons equals the number of electrons, and the identity of the atom is defined by the number of protons. Hydrogen has one, helium has two, lithium has three, etc. Figure 1 is a representation of an atom of sodium. It has 11 protons, 12 neutrons, and 11 electrons.

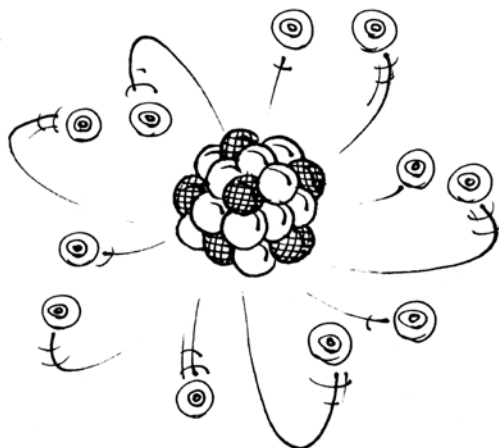


Fig. 1, Sodium Atom
Nucleus: 11 protons, 12 neutrons
Shell: 11 electrons orbit the nucleus

In writing, atoms are frequently represented by chemical symbols. The symbol is an abbreviation for the name of the atom. For example, Ca stands for calcium, and H stands for hydrogen. Other symbols are based on Latin names, such as Na for sodium (natrium) and K for potassium (kalium). Symbols are convenient and will be used frequently in the following text. Some of the commonly used symbols are shown in Table I.

Table I
Common Chemical Symbols

Hydrogen	H	Manganese	Mn	Silicon	Si
Lithium	Li	Iron	Fe	Nitrogen	N
Sodium	Na	Cobalt	Co	Phosphorous	P
Potassium	K	Nickel	Ni	Oxygen	O
Rubidium	Rb	Copper	Cu	Sulfur	S
Magnesium	Mg	Zinc	Zn	Fluorine	F
Calcium	Ca	Boron	B	Chlorine	Cl
Strontium	Sr	Aluminum	Al	Bromine	Br
Barium	Ba	Carbon	C	Iodine	I
Vanadium	V				

A collection of a single kind of atom is called an element. An element is a substance that cannot be destroyed or formed by ordinary chemical reactions. For example, sodium is an element. A piece of pure sodium consists of only sodium atoms, and they cannot be changed to atoms of any other elements. They will always be sodium atoms. However, they are capable of reacting or combining with atoms of other elements to form new materials called molecules. A molecule is a collection of two or more atoms connected by chemical bonds.

If sodium, a soft, silvery metal, reacts with chlorine, a greenish-yellow gas, sodium chloride (common salt), is formed. The substance formed is not similar to either of the components.

Ions are electrically charged particles. They possess an excess of electrons (negatively charged) or a deficiency of electrons (positively charged). Some molecules form ions when they are dissolved in water.

Sodium chloride (NaCl), dissolved in water, produces positively charged sodium ions (Na⁺) and negatively charged chloride ions (Cl⁻) (Fig. 2a). Potassium nitrate (KNO₃) produces positively charged potassium (K⁺) ions and negatively charged nitrate ions (NO₃⁻) (Fig. 2b). Ions can be either atoms, like sodium, potassium and chloride, or molecules, like nitrate.

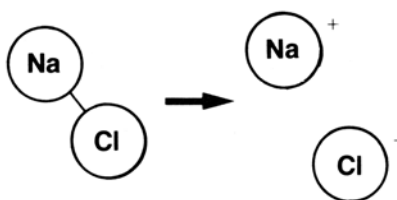


Fig. 2a, Dissociation of Molecules

(a) A sodium chloride molecule forms a positively charged sodium ion and a negatively charged chloride ion.

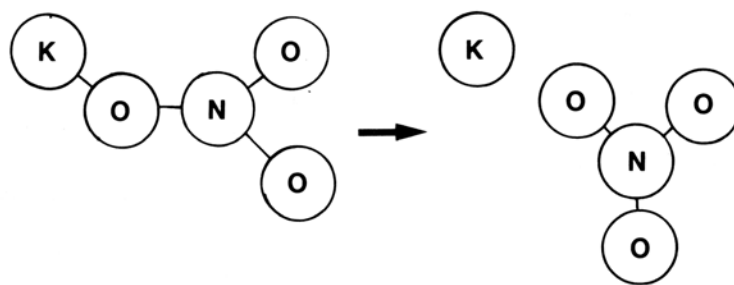


Fig. 2b, Dissociation of Molecules

(b) A potassium nitrate molecule forms a positively charged potassium ion and a negatively charged nitrate ion.

If both sodium chloride and potassium nitrate are dissolved in the same solution, it is impossible to tell what the original compounds were. Dissolving potassium chloride and sodium nitrate produces the same result (Fig. 3). It is often difficult to represent the components of complex solutions as neutral (uncharged) compounds. For this reason, the composition of seawater is given by concentrations of elements, such as sodium and magnesium, or ions, such as nitrate, rather than by concentrations of compounds, such as sodium chloride, magnesium sulfate, or sodium nitrate.

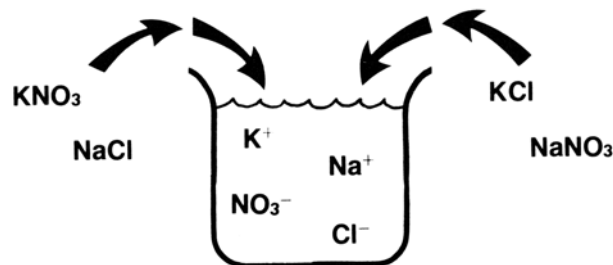


Fig. 3, Complex Solutions
 Identical solutions can be obtained by dissolving various combinations of different compounds.

Concentrations

Elements or molecules in seawater are usually shown as concentrations by volume or weight in solution. Modern literature uses the metric units of weight per volume, milligrams per liter (mg/l). Parts per million (ppm) is more popular in non-technical literature. The two terms, although different, are often used interchangeably. In this booklet, milligrams per liter will be used exclusively.

Many elements occur in solution as free ions, such as sodium (Na^+) or chloride (Cl^-); and it is convenient to simply report the concentrations of the elements (e.g., 10,500 mg/l Na^+). Other elements occur as components of molecular ions, such as nitrate (NO_3^-) or phosphate (PO_4^{3-}); and it is more convenient to report concentrations in terms of the element of interest.

For ammonia (NH_3), nitrite (NO_2^-), and nitrate (NO_3^-), concentrations are reported as milligrams per liter of ammonia-nitrogen ($\text{NH}_3\text{-N}$), nitrite-nitrogen ($\text{NO}_2^-\text{-N}$), and nitrate-nitrogen ($\text{NO}_3^-\text{-N}$). Similarly, for phosphate, phosphorous is reported ($\text{PO}_4^{3-}\text{-P}$).

This system permits easy, direct conversion. For example, 10 mg/l $\text{NH}_3\text{-N}$ will produce 10 mg/l $\text{NO}_2^-\text{-N}$ and ultimately 10 mg/l $\text{NO}_3^-\text{-N}$. When reading other books or articles, it is important to know which system is in use. To convert mg/l $\text{NH}_3\text{-N}$ to mg/l NH_3 , multiply by 1.3; to convert mg/l $\text{NO}_2^-\text{-N}$ to mg/l NO_3^- pt-(ion), multiply by 3.3; to convert mg/l $\text{NO}_3^-\text{-N}$ to mg/l NO_3^- (ion); multiply by 4.4.

Numbers in the latter system are always higher because they take in to consideration the contribution of the hydrogen and oxygen to the molecular weight. For example, 10 mg/l nitrite-nitrogen equals 33 mg/l nitrite ion, but both numbers represent the same concentration of nitrite. It's similar to your local weatherman saying that the temperature is 68 degrees Fahrenheit or 20 degrees Celsius. You know that, although the numbers are different, the temperature is still the same.

Components of Seawater

Seawater is an aqueous solution containing approximately 3.4 percent dissolved material. Many oceanographers have conducted determinations of the composition of seawater throughout the world, and a typical analysis is shown in Tables II a, b, c.

An examination of the Tables shows that seawater contains numerous chemical elements, many at extremely low concentrations. With sufficiently sophisticated analyses, it could probably be shown that seawater contains virtually every known element. However, in our discussion of aquarium water chemistry, only a few of these elements must be considered.

Major Ions

The components in Table IIa are the major ions found in seawater. These are also the major ions within the cells of living animals. They are responsible for maintaining electrical and osmotic balance within the cells, and for transmission of nerve impulses.

The complete absence of one of these major ions is fatal. A fish placed into a modified seawater solution that contained no potassium would soon die as a result of the chemical imbalance within the animal.

Table IIa
Major Ions Found In Seawater

Component	Concentration (mg/l)
Chloride	19,000
Sodium	10,500
Sulfate	2,600
Magnesium	1,350
Calcium	400
Potassium	380

The major ions are an area of little concern to the aquarist. Preparations of synthetic seawater always attempt to duplicate the concentrations of the major ions of natural seawater, and this can be accomplished with many different combinations or recipes of chemical compounds. Hundreds of such formulations are available in technical literature. Table III shows a number of different formulations, all of which result in solutions with a similar composition of major ions.

Since the major ions can be obtained from readily available chemical raw materials, it is probably safe to assume that all formulations of synthetic sea salts have succeeded in duplicating at least this part of the sea.

Minor Ions

Components in Table IIb are the minor ions. They occur at low concentrations, but are appreciably more abundant than trace elements.

Component	Concentration (mg/l)
Bicarbonate	142
Bromide	65
Borate	25
Strontium	8
Silicate	8

Bicarbonate is most important because it is the ion primarily responsible for buffering, or maintenance of pH. Borate also provides some contribution to the buffer system, but its effect is small in comparison. (The subject of pH will be discussed in a subsequent chapter.)

The importance of the remaining minor ions is less obvious. Silicate is essential to certain algae, and perhaps some animals. Bromide and Strontium, however, are not known to be essential for any biological process. It is likely that the complete absence of either would have no effect on the health of aquatic organisms.

This concept of extraneous vs. essential chemical elements is poorly understood by most aquarists. Its relevance will become even more apparent in the following section.

Trace Elements

Trace elements are those ions that are normally encountered at concentrations near or below 1.0 mg/l (Table IIc).

The designation of trace element refers only to the fact that the element is present in trace quantities. The term trace element does not imply any degree of importance with regard to the health of aquatic organisms.

Many aquarists fail to differentiate between trace elements and essential elements. They are two distinct groups. Not all trace elements are essential.

**Table IIc
Trace Elements**

Component	Concentration (mg/l)	Component	Concentration (mg/l)
*Fluoride	1.3	*Manganese	0.002
Rubidium	0.12	*Phosphorous	0.07
Aluminum	0.01	Thorium	0.00005
Lithium	0.18	Mercury	0.00003
Barium	0.03	Uranium	0.003
*Iodine	0.06	*Cobalt	0.00027
*Zinc	0.01	*Nickel	0.0054
Lead	0.00003	Cadmium	0.00011
*Selenium	0.00009	*Chromium	0.00005
Arsenic	0.003	Titanium	0.001
*Copper	0.003	*Vanadium	0.002
*Tin	0.003	*Molybdenum	0.01
*Iron	0.01	Others	Less than 0.10
Cesium	0.0005		

There is no reason to expect any benefit from the presence of, for example, Cesium or Thorium. There is no biological process that depends on their presence. Even though they are trace elements normally encountered in natural ocean water, they are not essential chemical elements. Most trace elements are not essential chemical elements. Those known to be essential are marked with an asterisk (*) in the Table.

Is it vital then for aquarists to attempt to ensure the presence of all essential trace elements in solution? No it is not, and, in fact, it is frequently impossible.

Many of the trace elements that are essential are heavy metals (e.g., Chromium, Manganese, Iron, Cobalt, Copper, and Zinc). Their importance to living organisms depends on the ability to interact with various organic molecules, such as enzymes, and form stable complexes with specific biological functions.

Water in an established aquarium contains significant quantities of dissolved compounds that may also be capable of forming stable complexes that make the metallic elements unavailable. Additionally, these complexes are readily removed from solution by activated carbon and other adsorbents.

Even in the absence of organic molecules and adsorbents, these elements may form insoluble inorganic compounds, such as carbonates or hydroxides which precipitate from solution. All these various mechanisms combine to make the aquarium water an unreliable source of many essential trace elements.

The problem of supplying essential trace elements is not one of water chemistry, it is one of nutrition. It is reasonable to expect that higher animals should obtain essential nutrients, including trace elements, from the food they eat. The best method of ensuring that your animals receive the nutrients they require is to provide a varied diet of high quality foods.

Commercial aquaculturists have realized this for some time, and commercial fish foods contain supplemental quantities of essential micro-nutrients. This attitude is now being seen at the hobbyist level, and many foods for ornamental fish are being formulated similarly.

If higher animals are your primary concern, there should be no need to add supplements to the aquarium water. However, if plants (algae) are a primary interest, the situation is different, because plants do not “eat” and must obtain their nutrients by direct absorption from the water.

Most aquariums that contain fish are also capable of supporting a modest growth of algae, because the waste products of the fish provide sufficient nutrients. However, for intensive algae culture, supplements are always necessary to restore nutrients that have been depleted from solution.

As interest in spawning marine fish grows, intensive algae culture is gaining increasing attention among marine hobbyists. It often becomes necessary to produce quantities of micro-algae which are, in turn, used to culture food for newly hatched larval fish. Useful algal growth supplements are commercially available, or may be prepared from one of numerous published formulas.

Algae are at the bottom of the food chain in nature; and it is likely that many of the nutrients that they absorb from solution ultimately supply the higher animals.

Table III Synthetic Seawater Formulations			
Formula A		Formula B	
Chemical	Concentration (g/l)	Chemical	Concentration (g/l)
NaCl	23.50	NaCl	27.190
Na ₂ SO ₄	4.00	MgCl ₂ • 6H ₂ O	5.110
KCl	0.68	MgSO ₄ • 7H ₂ O	6.930
H ₂ BO ₃	0.026	CaCl ₂ • 6H ₂ O	2.250
MgCl ₂ • 2H ₂ O	10.78	KCl	0.680
CaCl ₂ • 2H ₂ O	1.47	NaHCO ₃	0.200
NaHCO ₃	0.196	KBr	0.099
Na ₂ SiO ₃ • 9H ₂ O	0.030	SrCl ₂ • 6H ₂ O	0.040
		H ₃ BO ₃	0.027
		RbCl	0.0003
		FeSO ₄ • 7H ₂ O	0.0006
		NaSiO ₃	0.0043
		Na ₂ HPO ₄ • 12H ₂ O	0.0030
		Al ₂ Cl ₆ • 6H ₂ O	0.0008
		BaCl ₂ • 2H ₂ O	0.00009
		LiNO ₃ • 3H ₂ O	0.0007
		KI	0.00006
Formula C			
NaCl	24.72		
KCl	0.67		
CaCl ₂ 2H ₂ O	1.36		
MgCl ₂ • 6H ₂ O	4.66		
MgSO ₄ • 7H ₂ O	6.29		
NaHCO ₃	0.18		

The Chemical Environment

If one examines analyses of seawater, two important points are evident. First, proportions of all the major elements are remarkably consistent throughout the world. This is fortunate because it allows us to mix organisms that are native to many different locations.

Second, concentrations of inorganic nutrients (nitrogen as ammonia, nitrite and nitrate, and phosphorous as phosphate) and dissolved organic matter are quite low. This is a major chemical difference between seawater in the ocean and seawater in an aquarium.

Accumulations of these chemical species are characteristic of closed system aquariums and must be controlled by proper maintenance and filtration.

The following chapters discuss various water quality parameters that you are capable of controlling, and, in fact, must control. With a few unsophisticated accessories you can monitor a number of important factors and take appropriate action when necessary.

Salinity

Salinity is a measurement that indicates the amount of salt dissolved in water. Concentrations are commonly expressed as parts per thousand (ppt or 0/00). Normal seawater salinity is 35 parts per thousand, meaning that 1,000 grams of seawater contains 35 grams of dissolved salts.

Marine aquariums are usually maintained at salinities slightly lower than natural seawater, commonly 27 to 34 parts per thousand. This lower salinity benefits fish by requiring less energy to maintain osmotic balance. Reef aquariums with numerous invertebrates generally require a higher salinity, closer to natural seawater.

Aquarists ordinarily determine salinity indirectly by measuring specific gravity, which is a comparison of the density of a solution at a specified temperature (usually 15°C) to the density of pure water at a specified temperature (usually 4°C). A specific gravity of 1.100 means that at 15°C, the solution being measured is 1.100 times more dense than pure water at 4°C.





Fig. 4, Instant Ocean Hydrometer

Changes in the amount of salt dissolved in the water affect the specific gravity in a predictable manner. Therefore, each salinity has a corresponding specific gravity. If specific gravity is known, salinity can be found by use of conversion tables, such as Table IV.

Specific gravity is conveniently measured by use of a hydrometer, such as that shown in Fig. 4. Higher specific gravities cause the indicators to float higher in the solution. Lower specific gravities cause them to float lower. For ease of use, a hydrometer should be calibrated at a temperature near that of the water being tested. Most high quality aquarium hydrometers are calibrated for use at 75°F. Hydrometers calibrated at significantly different temperatures, such as 60°F, require corrections to obtain the actual specific gravity.

For most marine aquariums at 75°F, a reasonable estimate of salinity can be obtained by taking the last two digits of the specific gravity reading and multiplying by 1.35. (Example: Specific Gravity – 1.020. Multiply 20 x 1.35 = 27 ppt for estimated salinity).

In actual practice, most hobbyists dispense with the use of salinity and simply refer to the specific gravity. The range 1.020 to 1.023 is most common.

Table IV
Specific Gravity to Salinity Conversions

Specific Gravity	Salinity parts per thousand
1.015	20.8
1.016.....	22.0
1.017.....	23.3
1.018	24.6
1.019.....	25.9
1.020.....	27.2
1.021	28.5
1.022.....	29.8
1.023.....	31.1
1.024.....	32.4
1.025	33.7
1.026.....	35.0
1.027	36.3
1.028.....	37.6

pH

Most aquarists, freshwater and saltwater alike, begin their education in water chemistry when they are introduced to pH testing. The importance of proper pH was realized by the earliest aquarists, and an understanding of elementary concepts of pH will aid in understanding subsequent topics. (Keep in mind that pH is a complicated subject and that the following is greatly simplified.)

Principles of pH

Water is composed of two elements, hydrogen and oxygen. In a molecule of water, two hydrogen atoms are bound to a central oxygen atom (Fig. 5a). In a volume of water, some of the molecules dissociate, or separate, into hydrogen ions (H^+) and hydroxide ions (OH^-) (Fig. 5b). The pH represents the concentration of the hydrogen ions.

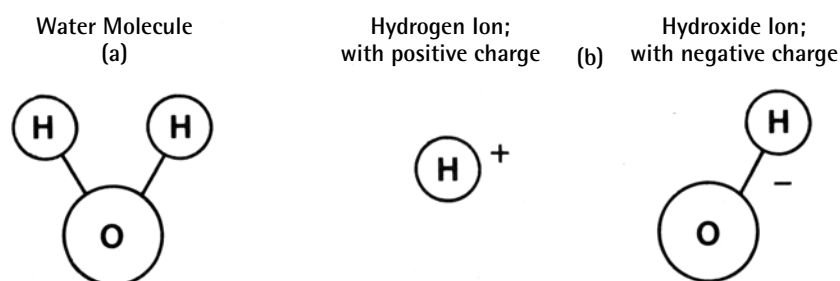


Fig. 5

Lower numbers on the pH scale represent higher hydrogen ion concentrations, and each pH unit denotes a tenfold change in concentration. That is, at pH 6, there are 10 times more hydrogen ions than at pH 7; at pH 8, there are 1/10 the number of hydrogen ions at pH 7.

When the number of hydrogen ions equals the number of hydroxide ions, the hydrogen ion concentration is represented by pH 7; and the solution is neutral. If the hydrogen ion concentration is increased, the pH falls below 7, and the solution is acidic. Conversely, if the hydrogen ion concentration is decreased, the pH rises above 7, and the solution is alkaline.

pH can be changed by addition of substances that affect the hydrogen ion concentration.

Hydrochloric acid (HCl) dissociates into hydrogen ions (H^+) and chloride ions (Cl^-). When added to a solution, there will be an increase in the overall hydrogen ion concentration and pH will drop.

It's easy to visualize that adding more hydrogen ions increases their concentration and lowers pH, but how is the hydrogen ion concentration lowered to increase pH? Obviously, one cannot reach into a solution and selectively pull out the hydrogen ions.

The hydrogen ion concentration and the hydroxide ion (OH^-) concentration are related. When one increases, the other decreases. Adding a substance that increases the hydroxide ion concentration lowers the hydrogen ion concentration. Sodium hydroxide (NaOH) dissociates into sodium ions (Na^+) and hydroxide ions (OH^-). Addition to a solution increases the hydroxide ion concentration and, consequently, decreases the hydrogen ion concentration, resulting in a higher pH.

Many substances affect pH when added to an aqueous solution. Some contain neither hydrogen ions nor hydroxide ions, but affect the pH indirectly.

Sodium bicarbonate dissociates into sodium ions (Na^+) and bicarbonate ions (HCO_3^-). Solutions of sodium bicarbonate are slightly alkaline and have a pH near 8.4. Additions of small amounts of strong acids or bases (alkalis) to solutions of sodium bicarbonate do not produce the expected change in pH because the hydrogen ions (H^+) or hydroxide ions (OH^-) are neutralized by the bicarbonate:



Unlike acids and bases, solutions of sodium bicarbonate have a relatively constant pH over a wide range of concentrations. Figure 6 is a simplified representation of this phenomenon.

In Figure 6, curve A represents a solution of strong acid; pH decreases rapidly as the concentration is increased. Curve C represents a solution of strong base; pH increases rapidly as the concentration is increased. Curve B represents a solution of a substance like sodium bicarbonate.

Consider a solution represented by point x on curve B. If hydrogen ions are now added to the solution, what happens? The hydrogen ions react with the bicarbonate and are neutralized. The bicarbonate concentration is decreased to point B, but we are in a region of the curve where a change in bicarbonate concentration results in little change in pH. Consequently, pH remains relatively unchanged in point y. From the curve, it is obvious that pH will remain relatively constant over a range of bicarbonate concentrations. This is the principle of buffering, or stabilization of pH.

Many chemicals can be used to prepare buffered solutions. In a marine aquarium, bicarbonate is the principal ion responsible for stabilization of pH. Biological action produces acidic substances that are subsequently neutralized. Continued addition of acid depletes the buffer, which must eventually be replenished or a dangerous drop in pH may result [Point z].

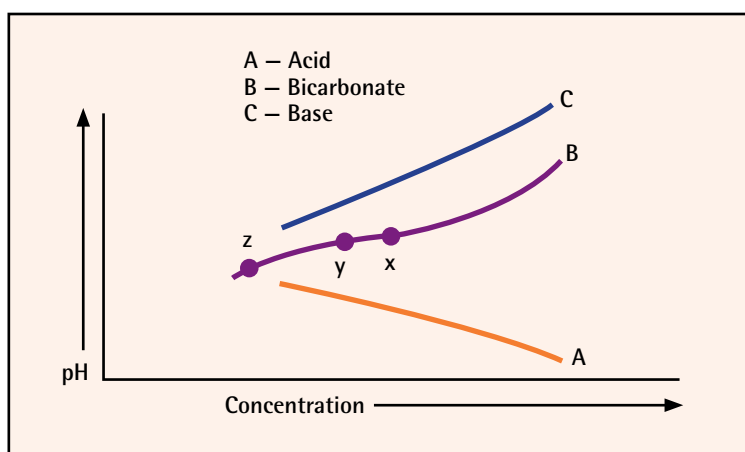


Fig. 6, pH Curves for Various pH-Influencing Substances

The capacity of a system to neutralize additions of acid is represented by a property called alkalinity. A solution with high alkalinity is relatively insensitive to moderate additions of acidic materials, whereas a solution with low alkalinity may experience a significant drop in pH under similar circumstances.

Proper pH is essential because availability of hydrogen ions is important to many biochemical reactions within living cells.

Small changes in pH can profoundly affect these reactions. Remember, a change of one pH unit means a tenfold change in hydrogen ion concentration.

The pH in a marine aquarium should be between 8.0 and 8.4, with 8.1 - 8.3 considered ideal. The pH and alkalinity are maintained by buffers that are present in the initial salt solution and, to some extent, by carbonate gravel and coral. As buffer is depleted, it must be replenished. This is accomplished by regular partial water changes, which may be supplemented by addition of sodium bicarbonate (baking soda).

Oxygen and Carbon Dioxide

Sufficient oxygen (O₂) is essential to marine aquariums. A warm water marine aquarium contains approximately 7 mg/l O₂ at saturation, and the oxygen concentration should always be maintained near saturation.

Fortunately, all that is necessary to accomplish this is vigorous aeration and circulation of the aquarium water. Gas exchange takes place at the air-water interface. Oxygen dissolves into the water to replenish that which has been used.

Animals (and plants in the dark) utilize oxygen to produce energy. In the process, carbon dioxide (CO₂) is produced, and released to the water.

Removal of carbon dioxide is as important as replacement of oxygen. If carbon dioxide builds up in the aquarium water, it becomes more difficult for fish to release it from their blood through the gills. Excessive carbon dioxide in the blood lowers its pH, which decreases the capacity for carrying oxygen. In extreme cases, a fish can suffocate even in the presence of excess oxygen.

In seawater at the proper pH (above 8), carbon dioxide is converted to bicarbonate (HCO₃⁻). At lower pH values the proportion of free carbon dioxide increases. Some of this may be slowly released to the atmosphere.

If aquariums are adequately aerated, and pH is properly maintained, there is little likelihood of encountering problems due to oxygen depletion or carbon dioxide accumulation.

Inorganic Nitrogen

Marine animals produce ammonia as a metabolic waste. Additionally, ammonia may be produced by bacterial action on uneaten food and other matter. The input of ammonia into aquarium water is constant, and ammonia is toxic to marine animals.

Ammonia in solution exists in two chemical forms: un-ionized (NH₃) and ionized (NH₄⁺) which, considered together, are referred to as total ammonia. Ionized ammonia is formed by reaction of un-ionized ammonia with a hydrogen ion (H⁺):



The proportion of ionized ammonia depends primarily on the availability of hydrogen ions, and is a function of temperature, salinity, and pH.

The strong influence of pH is easily understood when one recalls that pH is actually a measurement of the hydrogen ion concentration. In fact, because most aquariums operate within a narrow range of temperature and salinity, the contribution of these factors is insignificant. Table V shows how the proportion of ionized ammonia varies with changing pH.

Table V
Ammonia Equilibrium at Different pH Values at 75°F. (22°C)

pH	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5
% Ionized Ammonia (NH ₄ ⁺)	97.7	97.1	96.4	95.5	94.4	93.1	91.4	89.5
% Un-ionized Ammonia (NH ₃)	2.3	2.9	3.6	4.5	5.6	6.9	8.6	10.5

Equivalent amounts of total ammonia are more toxic at higher pH values. The Table shows that at the pH values normally encountered in a marine aquarium (pH 8.0 - 8.4), a significant proportion (4 -10%) of the ammonia is un-ionized.

It has long been suggested that un-ionized ammonia is the toxic form, and that increased toxicity at higher pH values is due to increased amounts of un-ionized ammonia. It is also possible that ammonia is toxic in both forms, that higher pH values increase the toxicity of both forms, and that the increase in un-ionized ammonia is coincidental.

So little is known about the mechanisms of ammonia toxicity that neither explanation has been proven scientifically. It cannot be denied, however, that ammonia is toxic and its presence in an aquarium is detrimental.

Fortunately, ammonia does not accumulate indefinitely. Certain bacteria obtain energy by oxidizing it and, in so doing, convert it to a less toxic molecule, nitrite (NO₂⁻).

Although less toxic than ammonia, nitrite is still dangerous. It affects the hemoglobin in the blood, making it less capable of transporting oxygen. At worst, this can result in death. At best, the animal is still subjected to stress from which it may or may not recover completely.

Results of recent research suggest that nitrite may not be nearly as toxic to some saltwater animals as was previously suspected. Unfortunately, this has not been demonstrated conclusively for the marine animals found in most aquariums and, until such time, any prolonged exposure to nitrite ions should be regarded as unsafe.

Nitrite, however, like ammonia, is susceptible to bacterial action, which converts it to relatively harmless nitrate ions (NO₃⁻). The process, by which ammonia is converted to nitrite, and subsequently nitrate, is called nitrification.

Conditioning (establishing the biological filter)

In newly set-up aquariums, ammonia accumulates as a result of the continuous input of animal wastes. Bacteria that utilize ammonia multiply, and eventually the ammonia is oxidized to nitrite as quickly as it is produced. As nitrite forms, it too accumulates until the bacteria that utilize it have multiplied sufficiently. Only nitrate continues to accumulate. The Chart in Figure 7 shows a typical nitrification sequence or nitrogen cycle.

The initial establishment of nitrifying bacteria is called conditioning or new tank cycle. It is accomplished by introducing one or two hardy animals to provide an ammonia source, and allowing sufficient time for bacteria to multiply.

During conditioning, ammonia increases, usually for a period of 1-2 weeks, ordinarily reaching a maximum concentration of 3-6 mg/l NH₃-N (Point A, Fig. 7). The level then decreases as populations of bacteria become established. After 3-4 weeks ammonia should be virtually undetectable.

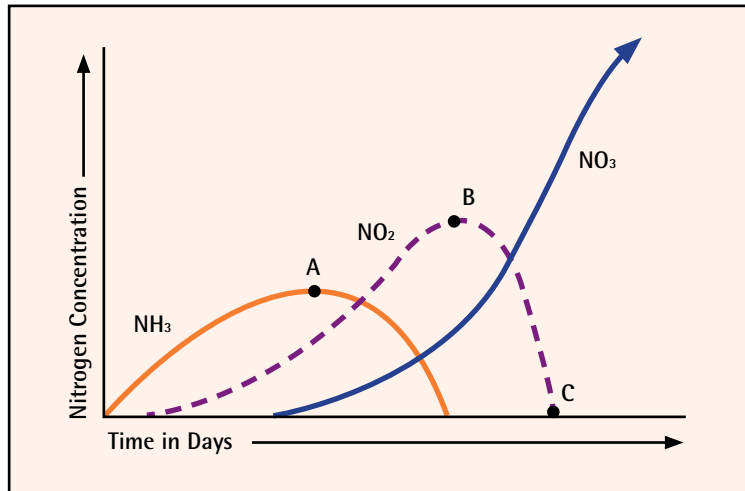


Fig. 7, Stylized representation of a typical ammonia-nitrite-nitrate sequence.

Nitrite appears shortly after ammonia. A maximum concentration is usually encountered in 2-4 weeks (Point B, Fig. 7), eventually decreasing to zero in 3-6 weeks (Point C, Fig. 7). This signals the completion of conditioning and the point at which additional animals can be safely introduced.

Addition of more animals occasionally produces a modest increase in ammonia and nitrite as bacteria equilibrate to accommodate the increased load. These changes should be temporary and subside quickly.

The conditioning period may be considerably shortened or eliminated completely by “seeding” a new aquarium with gravel from an older well established system. Use of 10 percent old, conditioned gravel will permit much more rapid increases in population than would otherwise be possible. In addition, you can add the bacteria directly, with products like BIO-Spira® or SafeStart.

Phosphorous

Phosphorous is encountered in the aquarium principally as dissolved phosphate (PO_4^{3-}).

Animal wastes are the primary source. Phosphorous concentrations increase as the water ages, but eventually level off. Maximum concentrations seldom exceed 3-6 mg/1 PO_4^{3-} -P. No toxicity problems have been directly associated with phosphate, and its presence is of little concern.

Phosphorous is an essential nutrient for algae, and its absence will severely limit growth of aquatic plants. An aquarium containing animals will always have phosphorous far in excess of that required by the “casual” algae that may be present. However, there are occasions when intensive culture of algae is desirable, perhaps for use as a food for other organisms. In such cases, especially in the absence of animals, it is likely that phosphorous, as well as other essential plant nutrients, will be depleted, and it will be necessary to maintain growth by use of supplements.

Organic Matter

Presence of significant concentrations of organic matter is an important difference between ocean water and aquarium water.

In an aquarium, animal wastes, excess food and excretions of plants result in accumulations of organic materials that are never encountered in the ocean. These substances can have a profound effect on aquarium life.

Non-living organic matter, either dissolved or particulate, is usually apparent upon visual examination.

Dissolved Substances

High concentrations of dissolved organic compounds are identifiable by observation of two situations. Either the water becomes highly colored, or the surface foams excessively when aerated. Frequently both occur simultaneously.

As aquarium water ages, it becomes increasingly yellow due to the presence of colored organic molecules. The condition is unsightly, but is controlled, to some extent, by regular partial water changes.

In some cases it is necessary to provide for additional means of removal. Activated carbon is frequently used for this purpose. Activated carbon in an auxiliary filter will usually keep the water sparkling clear, by adsorbing colored and other dissolved organic compounds.

Many organic compounds are surface active; they behave similarly to soap or detergents. Surface active compounds result in persistent foam on the surface of the water.

Surface active compounds are also conveniently removed by activated carbon, but an alternate method utilizes the foaming phenomenon.

A foam fractionator, or protein skimmer (Fig. 8] is a device that is designed to maximize the amount of foam produced, and continually remove it from the water surface. The foam-forming components are effectively removed from solution.



Fig. 8, Marineland Protein Skimmer

A third alternative is use of ozone to chemically “consume” large organic molecules. Ozone is frequently used in conjunction with activated carbon or foam fractionators for maximum efficiency and safety (activated carbon neutralizes excess ozone).

Removal of organic matter is necessary not only for the sake of appearance, but also for the health of the aquarium inhabitants as well. There is strong evidence to suggest that high organic levels interfere with normal growth and development of fish, and may contribute to increased susceptibility to disease. Also, bacteria utilize oxygen to consume biodegradable organic compounds. In effect, this increases the bio-load on the system, thereby reducing the holding capacity for desirable animals.

Particulate Matter

Particulate organic matter eventually accumulates in the filter bed as a fine, dust-like material called detritus. It is formed from solid wastes and from dissolved organic molecules that combine to form groups that are too large to remain in solution. Continued aggregation results in the highly visible detritus within the filter bed.

Detritus is of little concern unless it becomes so substantial that flow of water through the filter bed is impeded. However, since its appearance is unsightly, it is usually removed.

The most common method of removal is by gently “vacuuming” the gravel when water is being removed for a partial water change. Various mechanical devices are also available for cleaning the filter bed, and these may not require removal of the aquarium water to be effective.

If detritus removal is conducted on a regular basis, there is little likelihood of encountering problems associated with the cleaning. It should be noted, however, that the detritus has a high surface area that is available for growth of nitrifying bacteria. In fact, some of the nitrification capacity of the filter bed can be attributed to the bacteria upon the detritus particles.

If allowed to accumulate for an appreciable time (several months), a significant portion of the nitrifiers may be on the detritus. Its removal could result in a substantial decrease in biological filtration capacity. In an aquarium that is loaded near capacity, this could be disastrous.

An aquarium maintenance program should always include regular cleaning of the surface of the filter bed.

Copper

Copper is given special attention because it is extensively used as a medication for protozoan diseases of fish. Levels of copper, used for therapeutic purposes, are far in excess of those normally encountered in nature.

Elevated copper levels may be dangerous to fish and invertebrates, but copper has a long history of successful application when utilized properly. However, it is a heavy metal, and is subject to the same instabilities discussed previously in the Trace Element Section. This makes proper utilization difficult.

Copper treatment should be maintained within a safe, yet effective, therapeutic range (0.10 - 0.20 mg/l) for at least 10 days. When copper sulfate is used, the copper concentration decreases soon after addition to the aquarium water, and the level must be maintained with additional copper sulfate.

An accurate copper test kit is valuable, but most aquarists rely on the chance that regular additions, according to manufacturer’s recommendations, will be sufficient. When following recommendations for regular additions, the copper concentration that results depends on numerous conditions that vary in different aquariums. The actual concentration that results may be useless, effective, toxic, or somewhere in between. Without an accurate analysis, it is impossible to be certain.

For this reason, it is always preferable to utilize a separate aquarium for treatments. To attempt treatment of a display tank with only one or two unhealthy specimens is flirting with disaster.

During treatment, do not filter with carbon or other adsorbents. They remove copper quickly, and are, in fact, an excellent means of reducing the concentration in an emergency.

Never use copper if invertebrates are present. Many are especially sensitive to it and may be killed.

Recently developed medications contain copper that has been reacted with an organic substance to produce compounds that are more stable in solution, and less toxic to fish. They are also less toxic to parasites, and higher copper concentrations, which vary with different products, are necessary to be effective. Their primary advantage is stability in solution. Once an effective therapeutic level has been established, subsequent additions are unnecessary or greatly reduced. Most are still conveniently removed by activated carbon or other adsorbents.

Water Chemistry as a Guide to Aquarium Maintenance

Testing may be used to help indicate the quality of water in the aquarium. By itself, however, testing is neither beneficial nor detrimental to water quality, and is useless unless the aquarist is aware of appropriate action, and prepared to take it, when tests indicate that it is necessary.

The situations discussed here are those most frequently encountered by today's aquarists: new aquariums, established aquariums, and hospital or medication tanks. A fourth situation, high density rearing or hatchery aquariums, is uncommon and beyond the scope of this booklet.

In addition, discussion is limited to those situations that can be analyzed with test equipment that is easily obtained by hobbyists.

Conditioning of New Aquariums (establishing the biological filter)

- **Note: recent discoveries and technologies have proven that addition of proper nitrifying bacteria, found in products like BIO-Spira® and SafeStart, will drastically reduce cycle time and prevent harmful conditions from ammonia and nitrite.**

In conditioning, or establishing the nitrogen cycle of new aquariums, a few hardy animals are introduced to provide a source of ammonia. Simply setting up the aquarium and letting it operate for several days without animals does nothing. Animals must be added to provide a source of ammonia for the nitrifying bacteria.

The aquarium experiences elevated ammonia levels followed by elevated nitrite levels. Both subside when sufficient populations of nitrifying bacteria are established.

Monitoring ammonia throughout the conditioning process is of questionable value. Little can be done to prevent or compensate for the inevitable rise in ammonia. Even knowing when the ammonia concentration falls to zero is unimportant. This is usually accompanied by high nitrite levels, and it is still unsafe to increase the population of animals until the nitrite concentration is zero, indicating the completion of the initial conditioning.

Nitrite appears shortly after adding animals to a new aquarium, and the maximum is usually encountered in 2 - 4 weeks. The concentration should decrease to zero in 3 - 6 weeks.

Monitoring nitrite during conditioning provides a convenient measurement of progress and will indicate the point at which additional animals can be safely introduced. An approximate position on the nitrite curve (Fig. 7) can be estimated by comparing measurements on consecutive days. Once the concentration begins to decrease, it is usually only a short time before conditioning is complete.

In aquariums that have not been seeded with a substantial amount of conditioned gravel, nitrite concentrations can exceed 5 mg/l NO₂-N, and a test should be chosen that is capable of measuring the high concentrations that are encountered during conditioning. Tests that have only low range capability are not as useful because they indicate beyond their maximum readable concentration for much of the conditioning period. Of course, it is essential that the test clearly indicate when the nitrite concentration has fallen to zero.



Established Aquariums

Monitoring ammonia and nitrite in an established aquarium provides information on the condition of the biological filter. Nitrification in the filter is so efficient that ammonia and nitrite should be virtually undetectable.

Presence of ammonia or nitrite indicates that the filter is not capable of handling the biological wastes to which it is subjected. Common causes include:

- | | |
|-------------------------------|----------------------------------|
| (1) Overcrowding | (4) Medications |
| (2) Overfeeding | (5) Insufficient circulation |
| (3) Undiscovered dead animals | (6) Irregular cleaning of filter |

Overcrowding is frequently difficult to diagnose because there is no convenient method of determining the carrying capacity of an aquarium. The maximum acceptable animal load depends on a number of factors, including surface area and depth of the filter bed, particle size of filtrant, and flow rate through the filter. In addition, the type of animal will also affect the amount that can be safely maintained.

There are numerous “rules of thumb” for the maximum allowable concentration of fish. One author may suggest no more than 3 inches of fish per square foot of filter area. Another may indicate that ½ inch of fish per gallon is acceptable. There is much confusion.

On a purely subjective basis, it is safe to say that if an aquarium looks too crowded, it probably is. Frequent fighting and general irritability of the fish are other possible indications.

If elevated ammonia or nitrite levels persist, and you have ruled out the other possible causes, then you may reasonably suspect overcrowding. Removal of some of the animals is necessary to reestablish balance.

Overfeeding and undiscovered dead animals are similar situations. In both cases the decomposing organic matter provides ammonia, which increases the load on the biological filter. If the capacity of the filter is exceeded, elevated ammonia or nitrite levels will be encountered.

In either situation, the offending material must be removed, either by net or by vacuum siphoning. The aquarium should then stabilize quickly.

Care should be taken when feeding to make sure that significant amounts of food do not go uneaten. The aquarium should be observed frequently to determine that all animals are alive and healthy. Pay special attention to soft-bodied animals, such as anemones, which can decompose rapidly and foul the aquarium.

Medications may have adverse effects on the bacteria in the filter bed. If elevated ammonia or nitrite levels are observed shortly after medicating, then the biological filter has probably been damaged.

If possible, the animals should be moved to another holding facility while a substantial water change (50 percent or more) is conducted. Filtration with activated carbon may also help to remove the medication. Under the best circumstances the bacteria recover quickly and the animals may all be safely reintroduced. In some situations, it may be necessary to increase the population slowly, just as in a newly established aquarium.

Refrain from medicating in display aquariums. Such treatments are better performed in “hospital tanks” that are reserved specifically for the purpose of medicating. Conditions of treatment are easier to control and there is no risk to healthy specimens in the display tank.

For optimum performance, the biological filter must receive a constant, substantial flow of oxygenated water. If circulation through the filter bed decreases appreciably, incomplete nitrification can occur and ammonia or nitrite may be detected.

The situation is easily remedied by restoring normal circulation. The most common causes of decreased circulation are:

- (1) Plugged air diffusers in airlift tubes
- (2) Kinked air lines
- (3) Worn out or weak air pumps
- (4) Worn out motors or other power filter components

The problem should be corrected by repair or replacement of the defective item.

An appreciable portion of the filtration capacity of a biological filter may be due to bacteria on the surface of detritus particles. If allowed to accumulate for some time, the removal of this detritus results in an appreciable loss of nitrifying ability, and ammonia or nitrite are detected.

If this occurs, it may be necessary to transfer some of the animals to a separate holding facility to allow the biological filter to re-equilibrate.

To prevent such occurrences, the filter bed should be cleaned regularly to remove accumulating detritus, by lightly vacuuming. Usually this is accomplished during removal of water for regular partial water changes.

Aquarists frequently ask, "What is the maximum exposure level for ammonia and nitrite?" or "How much can the fish tolerate without being seriously affected?"

Many studies have been conducted to determine tolerance levels for various species of fish. Unfortunately, the studies are conducted on fish that are commercially valuable, such as salmon and trout, and the results are not necessarily applicable to the types of fish in marine aquariums. Precise information concerning tolerance limits of ornamental aquarium fish is not available.

Nitrification in the filter is so efficient that ammonia and nitrite should be undetectable. The tolerance of the fish to ammonia or nitrite is irrelevant. Elevated levels of ammonia or nitrite should alert the aquarist to a potential problem. If the condition exists for more than a day or two, then the problem must be found and corrected.

Nitrate, the end product of nitrification, is the only form of inorganic nitrogen that is detectable in a healthy aquarium. Its concentration increases continuously, unless limited by regular partial water changes.

Since nitrate is relatively non-toxic, water changes are not conducted only for the sake of limiting nitrate. There are additional benefits that, although less obvious, are perhaps more important.

Nitrate accumulation is accompanied by other changes. Buffers are depleted and pH decreases. Dissolved organic materials increase and phosphate increases. Concentrations of other inorganic ions also change. The environment becomes increasingly unlike the natural environment. This contributes to increased stress for the aquarium inhabitants, and ultimately may result in disease or loss.

It is in the best interest of the aquarist to control these changes as much as is reasonably possible. We can never hope to duplicate the stability of the sea, but we can limit the inherent instability and inefficiency of the aquarium with a conscientious aquarium maintenance program. Nitrate testing can provide valuable information for this program.

The rate of increase in the nitrate concentration is a function of the bio-load on the system. Many other changes that occur also tend to be in proportion to the bio-load. Thus, nitrate is a convenient “yardstick” to measure the relative biological age of the water. Maintaining reasonable nitrate levels through periodic partial water changes also helps to control and moderate other changes that are occurring in the water.

A maximum concentration of 20 mg/1 NO₃⁻-N is recommended. However, in non-critical situations, such as ornamental display aquariums, this level is frequently exceeded without serious consequences. For these applications, maximum concentrations of 20 - 40 mg/1 NO₃⁻-N are probably acceptable.

Each month, 25 percent of the old aquarium water should be replaced with fresh saltwater, and this is usually sufficient to maintain nitrate at reasonable concentrations. Other activities, such as breeding of fishes or feeding experiments, usually require more control and lower concentration limits. In these situations, nitrate testing is indispensable because monthly water changes may not be sufficient to maintain the desired water quality, and, in the absence of sophisticated equipment, nitrate level is the most convenient indicator of the condition of the aquarium water.

In addition to nitrate, the nitrification process also produces acid. This acid depletes buffers and results in steadily decreasing pH, which, if uncorrected, will fall below ideal levels. Monitoring pH allows the aquarist to make corrections before the situation becomes dangerous.

Marine aquariums operate comfortably in a pH range of 8.0 to 8.4 with 8.1 to 8.3 considered ideal. The aquarist should strive to maintain pH near the ideal, and to avoid wide fluctuations.

Occasionally the regular partial water changes are sufficient to restore depleted buffers and control pH fluctuations. However, frequently it is necessary to add buffer between water changes in order to maintain the desired stability. Aquarium-safe buffers should be added when the pH approaches the low end of the safe range.

Always dissolve the additives in a small amount of water before adding it to the aquarium. Make changes gradually; no more than 0.1 pH unit per day. It is always better to make small corrections frequently, rather than large corrections occasionally.

A common misconception holds that use of the proper gravel, such as dolomite or crushed coral, is sufficient to prevent low pH. In fact, at the normal pH of a marine aquarium, the effect of the gravel is slight. The effect of the gravel becomes significant only when the pH falls below 8.0, beyond the recommended range. The gravel alone will not prevent significant fluctuations in pH; some action on the part of the aquarist is always necessary.

Hospital Tanks

A hospital tank is an auxiliary aquarium that is reserved for isolation and treatment of sick fish. Typically, it is used for short periods and does not have a functional biological filter.

Without a functional biological filter, ammonia is the first waste product that will accumulate. Since a diseased fish is already in a weakened condition, the ammonia must be controlled to prevent subjecting the fish to additional stress.

Ammonia can be controlled by partial water changes, and monitoring ammonia will indicate when a change is necessary. Depending on the size of the tank and the size of the fish, frequent water changes may be necessary to minimize ammonia toxicity problems. It may even prove difficult to maintain less than 1.0 mg/l ammonia-nitrogen. The ammonia level should be maintained as low as is reasonably possible.

Considering the inherent difficulties with hospital tanks, many aquarists question their necessity. However, medication of established display aquariums should be avoided. The effects on the system are often unpredictable. Additionally, should the aquarist encounter unexplained problems in the future, he will always be uncertain whether residual medications are a contributing factor.

A medication is a toxic substance. Although intended primarily to control parasites, few medications are completely harmless to fish. Obviously, treatment of a disease can be accomplished only with medications that are more toxic to the parasites than to the fish.

Some medications have a wide margin of safety. For others the effective therapeutic concentration is only slightly less than the level that is toxic to fish. In any event, the animals are subjected to a stress that may range from moderate to severe.

In addition, some medications are harmful to the biological filter, and use in a display aquarium can have serious long-term consequences, as discussed previously.

Healthy fish should not be subjected to the potential hazards of medications. A hospital tank is the means of ensuring safe treatment without risk to healthy fish.

All Systems

Temperature and salinity should be monitored in all aquariums, whether they are new, established, or hospital tanks.

Temperatures of 70° to 80°F (21° to 26°C) are ideal. Occasionally, during hot weather, it may be impossible to maintain low temperatures.

At elevated temperatures, the oxygen dissolving capacity of water is less, while the metabolism of the animals is speeded up, and they actually require more oxygen. In effect, the holding capacity of the tank is decreased. In such situations, it may become necessary to lower the population of animals in the aquarium.

Ideal salinities are 27 to 35 parts per thousand, which correspond to specific gravities of approximately 1.020 to 1.026. Once the proper salinity is obtained, occasional replacement of fresh water lost to evaporation will maintain the desired salinity with minimal fluctuations. Water used for partial water changes should be adjusted to the salinity of the aquarium before use.

Water in hospital tanks should be adjusted to the salinity of the appropriate display tank.

To increase salinity, add more salt. To decrease salinity, add more fresh water.

For both temperature and salinity, consistency is more important than absolute value. Temperature should not fluctuate by more than 1 or 2°F (1°C) in a 24 hour period. During warm periods, adjust the aquarium heater to a temperature only slightly below the maximum temperature, to prevent excessive cooling during the night. Salinity should not fluctuate more than 1.0 part per thousand (0.001 specific gravity units) per week.



Summary and Comments

Monitoring of various water chemistry parameters can provide valuable information to the serious marine aquarist.

Routine monitoring of ammonia and nitrite may indicate a developing problem in an established aquarium. Measurements of nitrate and pH help develop a reasonable timetable for routine maintenance, which is the aquarist's most valuable tool for continually providing a healthy environment within the aquarium.

In newly set-up aquariums, nitrite measurements are an indicator of progress in the conditioning sequence.

Temperature and salinity measurements are aids to maintaining a more stable environment.

Other measurements serve useful purposes in special circumstances, but are not routinely employed by most aquarists. For example, phosphate levels may be of interest for intensive algal culture.

In choosing test equipment, always remember that the value of the test depends on its accuracy. The accuracy of a test is a function of two factors – the accuracy of the standards and the reliability of the reagents.

Standards, or comparators, are generally one of three types: colored liquids in sealed tubes, colored plastic films or chips, and printed paper. Liquid and plastic types are usually more reliable because paper types tend to discolor easily. Never store any standard in direct sunlight or it will most certainly fade and become useless.

Reliability of reagents depends on the type of reagent and its stability upon storage. Any reagents that have appreciably discolored should not be used. In general, liquid reagents are more prone to deterioration than dry reagents. Refrigeration will extend the life of liquid reagents.

When in doubt, attempt to analyze a solution of a known concentration, to test for accuracy. If such a solution is not available, at least attempt a duplicate analysis to test for repeatability.

Reasonable care and attention will benefit the aquarist who attempts to utilize the information that can be gained through water analysis.



Glossary

ABSORPTION – The taking up of one substance by another, usually of a liquid by a solid, involving weak chemical or physical forces. Water is absorbed by a sponge, but it is weakly held, and may be easily removed by squeezing or drying.

ADSORPTION – The taking up of one substance by another involving strong chemical or physical forces. Methylene blue, a chemical dye, can be adsorbed by activated carbon, and then is extremely difficult to remove from the carbon.

AQUEOUS – Of or pertaining to water.

BIO-LOAD – The sum of the contributions and requirements of all the living organisms in an aquarium.

BUFFER CAPACITY – The ability of a solution to resist changes in pH.

COMPLEX – A metal ion surrounded by an organic molecule to which it is tightly bound. The organic molecule insulates the metal ion and reduces its activity in solution.

COMPOUND – A collection of atoms of two or more elements, connected by chemical bonds.

CONDITIONING – The process of establishing a biological filter in the aquarium. Sometimes called run-in or cycle.

DENSITY – Weight per unit volume. For example, pounds per cubic foot.

DETRITUS – Loosely packed, insoluble solids that accumulate on the aquarium floor.

DISSOCIATION – The reversible breaking apart or separation of a molecule into two or more parts.

ELECTRON – An elementary particle of an atom that carries a negative electrical charge.

ENZYME – A large molecule that promotes biochemical reactions.

EQUILIBRIUM – A state of balance between opposing forces. Chemical equilibrium is a condition in which two opposing chemical reactions are occurring at the same rate.

HEMOGLOBIN – An iron-containing pigment that is responsible for oxygen transfer in the blood of many animals.

INORGANIC – Referring to chemical compounds that do not contain carbon.

MILLIGRAMS PER LITER – A unit of concentration measurement in the metric system that denotes weight per volume. A milligram is approximately 1/28,000 of an ounce; a liter is slightly larger than a quart.

NEUTRON – An elementary particle of the atom that is not electrically charged.

NITRIFICATION – The sequence of oxidation, by bacteria, of ammonia to nitrite, and nitrite to nitrate.

NITRIFIERS – Bacteria that are capable of oxidizing ammonia or nitrite.

ORGANIC – Referring to chemical compounds that contain the element carbon.

OSMOTIC – Referring to flow or diffusion of substances through a semi-permeable membrane, such as a cell wall.

OXIDATION – Chemical addition of oxygen to a substance, often by a series of reactions. Oxidations may be vigorous (fire) or mild (bacterial oxidation of ammonia).

OZONE – A highly reactive molecule composed of three atoms of oxygen. A molecule of normal atmospheric oxygen is composed of two atoms of oxygen.

PARTS PER MILLION – A unit of concentration measurement that denotes weight per weight in equivalent units. One part per million can mean one gram per million grams or one pound per million pounds, or any other unit of weight may be used.

PROTON – An elementary particle of the atom that carries a positive electrical charge.

PROTOZOA – Microscopic animals, many of which consist of only a single cell.

SATURATION – State of being filled to the maximum extent.

SOLUTION – A mixture of two or more substances that is uniform throughout. A sample taken from a solution will have the same composition and properties as every other sample taken from the same solution, regardless of the size of the samples.

SURFACE ACTIVE – Capable of modifying the properties of a liquid at a surface or interface.

A marine aquarium is like a complex, living organism.

Each component – fish, invertebrates, algae, and even bacteria – must remain healthy to ensure continued survival of the total system.

Water is the common bond between everything in the aquarium, and, more than any other factor, the quality of the water affects the health of this system. Maintenance of excellent water quality should be the first priority of every aquarist.

A few simple tests can tell if the system is running smoothly or alert us to potential problems. A basic understanding of water chemistry is a valuable asset, especially because it gives us a better appreciation of the importance of water quality.

The popularity of marine aquariums is growing dramatically, as more hobbyists realize that marine aquariums are no more difficult than fresh water aquariums. Marine fishes are being bred with increasing frequency, offering an exciting challenge to aquarists, both amateur and professional. Marine algae are becoming available, opening endless possibilities in aquarium decor.

The aquarist of today is at the leading edge of an exciting hobby. This book provides the foundation upon which to build with personal experience.



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