

Ions, Atoms and Charged Particles

By Francis S. Key and George Maass, PhD

Colloidal silver has been shown to be very effective as a bacteria-fighting agent by Gibbs¹. This paper will discuss colloidal silver – its nature and how it is produced. The discussion will focus specifically on the forms of silver that are found in colloids of silver, specifically, silver ions and silver particles and the electrical charges associated with each. Many non-scientific writers confuse ions and charged particles and use the terms interchangeably when describing colloidal silver. Others refer to colloidal particles as though they are single atoms of silver. Much has been written about silver particles having a *positive* charge, which is false. It is no wonder then that lay people trying to learn about colloidal silver become confused and have a hard time grasping the science involved with the subject matter when so much of what they read is scientifically flawed.

Since the real science involved in understanding colloidal suspensions requires an understanding of the underlying principles, it is important to have a clear understanding of the differences between atoms, ions and charged particles.

What is colloidal silver and why is this important?

While a colloid can have many forms, colloidal silver is one type of colloid that consists of **solid particles suspended in a liquid**. The solid is *very small* particles of metallic silver and the liquid is water. *Very small* particles in this context refer to particles whose diameter is measured in nanometers². A silver colloid then must have silver particles in suspension. Colloidal silver also contains another form of silver called *ions*. The difference between solutions, colloids, and suspensions is defined by the size of the particles:

solutions	<10 ⁻⁹ m (less than 1 nm)
colloids	10 ⁻⁹ m to 10 ⁻⁶ m (1 nm to 1000 nm)
suspensions	> 10 ⁻⁶ m (larger than 1000 nm)

Various forms of silver

Colloidal silver is generally produced by electrolysis when an electric current is passed through a series circuit consisting of a silver electrode and de-ionized (DI) water. The current can be either alternating current (AC) or direct current (DC). The current flow causes Ag⁰ (metal) and Ag⁺ (ions) to migrate from the electrode into the DI water. AC processes tend to be more efficient than DC in limiting the ionic concentration. It is generally assumed that water ionizes to H⁺ and OH⁻, and that the H⁺, in the form of the hydronium ion, H₃O⁺, migrates to the cathode, where it is reduced to hydrogen gas, H₂, which is liberated. The electrons taken from the cathode are replaced at the anode when Ag metal goes into solution as Ag⁺.

Therefore, colloidal silver consists of silver in two distinctly different forms, metallic silver particles and ions. The total amount of silver that is reported as the *silver concentration* (in parts per million) is the sum total of the silver contained in the particles and the silver contained in the silver ions. Accurate measurement of total silver content requires the measurement by either atomic absorption or atomic emission of the silver atoms. An Atomic Absorption Spectrophotometer (AAS) is typically used for accurate results. To measure the concentration of silver ions by atomic absorption requires that the particles first be removed by centrifugation leaving only the ions. Alternatively, an Ion Selective Electrode (ISE) can be selected that only responds to the silver ions in solution. ISE measurements are less accurate than AAS and are generally accurate to within about 2%. The concentration of silver particles is determined by subtracting the ionic concentration from the total

1 Silver Colloids – Do they work? By Ronald J. Gibbs 1999, ISBN 0-9676992-0-7

2 Nanometer (nm) – billionth of a meter. A nanometer is the unit of measure used to measure the wavelength of visible light. For example, the thickness of a human hair is 76,200 nanometers or 3 thousandths of an inch.

silver concentration.

Typically, silver ions make up 75 to 99 percent of the total silver while only 1 to 25 percent of the total silver is particles. A solution containing only ionic silver and no particles is not a colloid since there are no solid silver particles in suspension. On the other hand, if 100 percent of the silver was particles and no ions were present, the solution would be a pure colloid. One measure of the quality of a silver colloid is the percentage of silver particles. Ideally, all the silver content would be in the form of particles with no silver ions.

The authors believe that a truer representation of the contents of a colloidal silver product would be to report on the label the silver concentration of only the silver particles. An alternative would be to report what percentage of total silver is contained in the particles and what percent is ionic.

Silver atoms

A single silver atom can be considered to be an atomic sized particle of metallic silver. It is the smallest size of silver matter that exists. The diameter of a single silver atom is 0.288 nm. While it is theoretically possible to have a particle of metallic silver that consists of a single atom, in practice particles are much larger and consist of many atoms. Just for reference, a particle one nanometer in diameter would consist of 31 silver atoms, and a 5 nm diameter particle would be about 3900 atoms while a 20 nm diameter particle would contain about 250,000 silver atoms. The particle size typically observed in colloidal silver has been measured in the range of 5 to 200 nanometers. Such measurements are performed using a Photon Correlation Spectrometer (PCS) that can measure down to 1 nm. In our laboratory a Malvern Zetasizer 3000HS is used to make such measurements.

Silver ions

A silver ion is a single atom of silver that is missing one electron from its outer orbit. The diameter of a silver ion is 0.230 nm, which is slightly smaller than an atom owing to one less electron. **Ag** has the electron configuration $[\text{Kr}]4d^{10}5s^1$. When $\text{Ag} - e^- \rightarrow \text{Ag}^+$, it is the $5s^1$ electron which is lost. The missing electron causes the ion to be positively charged and also changes the physical properties in some very dramatic ways. Metallic silver is not soluble in water, but ionic silver has a finite measurable solubility. Typically, silver is dissolved in an acid such as nitric acid to form silver nitrate. When silver is dissolved, it is no longer metallic silver. It is not visible even under the most powerful microscope and it does not reflect light. Even a solution saturated with Ag^+ ions has no *Tyndall effect*³, but a colloidal Ag does, even in concentrations as little as 0.1 ppm. The solubility product constant, K_{sp} for AgOH is 1.52×10^{-8} , which means that, in a neutral solution, one could have 9.2×10^{22} Ag ions per liter without getting precipitation.

In summary, a silver ion is positively charged because it lacks an electron. An electron has a negative charge. Take away an electron and the ion so formed assumes a positive charge. The charge attributed to ions is *ionic charge* and it is due to the gain or loss of electrons. This is not the same as a particle that may have a charge. *Particle charge* is due to the adsorption of charged species. In fact the silver particles found in colloidal silver are negatively charged, not positive like the ions.

Charged particles

Silver particles that are suspended in pure water to form a colloid will assume a negative charge that is called the zeta potential. Most solids develop a negative zeta potential when dispersed in water of low ionic concentration. The charge acquired by the particles is partly due to the adsorption of ions in the solution. The surface charge gives rise to a potential distribution around the particle: the value of this potential at the *slipping plane*⁴ is defined as the zeta potential.

3 Tyndall effect – The scattering of light as it passes through a medium containing small particles.

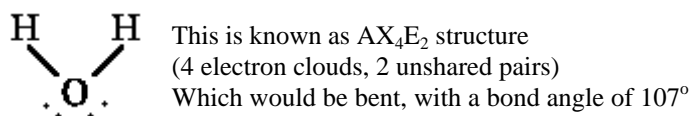
4 Slipping plane – An electrical double layer exists around each particle. The liquid layer surrounding the particle exists as two parts; an inner region (Stern layer) where the ions are strongly bound and an outer (diffuse) region where they are less firmly associated. Within the diffuse layer is a notional boundary known as the slipping plane, within which the particle acts as a single entity.

The zeta potential of colloidal silver solutions that contain silver ions will typically be in the range of -35 to -45 millivolts (mV) depending on ionic content. The zeta potential of silver colloids that contain no silver ions will have a higher negative potential of about -50 mV. The higher the ionic content, the less negative the zeta potential since the positive charge of the silver ions will cancel some of the negative charge on the particles.

Particles have a negative charge

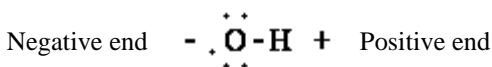
In the case of colloidal silver, the silver ions present are positively charged, so how do the silver particles acquire a negative charge? Silver ions are created during the electrolysis that makes colloidal silver. The creation of silver ions would tend to make the net charge of the solution positive. However, solutions always have a net charge very close to zero because Coulomb force is extremely strong, and even a tiny charge imbalance creates enough voltage to ionize everything in-between and cancel it. Ionization breaks the water molecule into hydrogen H^+ and hydroxyl ions OH^- , which are negatively charged. The negative charge of the hydroxyl ions counters the positive charge of the silver ions and maintains a solution of whose net charge is zero. Thus the negative hydroxyl ions are created at the same time that the positive silver ions and silver particles are created. The hydroxyl ions are non-metallic ions that bond to the atoms of the silver particles thus imparting their negative charge to the particles.

Oxygen has 6 valence electrons and 2 hydrogens have one each, for a total of 8. Therefore the *Lewis structure*⁵ of H_2O is

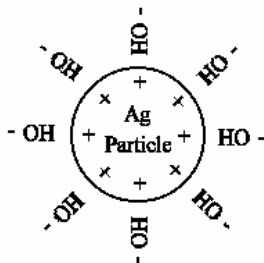


The actual bond angle is 105° , due to the repulsion of the 2 unshared pairs.

When H ionizes as H^+ , that leaves the non-metallic OH^- anion⁶, which would have the following structure and would be polar



As in the case of *sols*, when the OH^- anion approaches the Ag atom, although that atom is neutral, the first thing it sees is the $5s^1$ electron, therefore, the H , or positive, end of the anion is attracted to the atom, leaving the negative end sticking out into the solution. This behavior is well documented for sols (colloidal particles which have charged particles adsorbed on them). The mutual repulsion of the similar charges then stabilizes the colloid by keeping the particles from agglomerating.



⁵ G. N. Lewis – Valence and Structure of Atom and Molecules, Dover Publications, Inc. NY 1966

⁶ Anion – A negatively charged ion, i.e. an ion that is attracted to the anode in electrolysis.

Why are the positive silver ions not attracted to the negative hydroxyl ions? The force of attraction or repulsion of electric charges is inversely proportional to the dielectric constant of the medium surrounding the charges. Water has a very high dielectric constant of about 80 at room temperature. This means that the two opposite electric charges in water attract each other with a force only 1/80 as strong as in air or a vacuum. Thermal agitation of the ions is great enough to cause the ions to dissociate. It is common that ions of opposite charge coexist in solution. For example, when salt is dissolved in water the resulting solution contains sodium ions (Na⁺) and chloride ions (Cl⁻) of opposite charge.

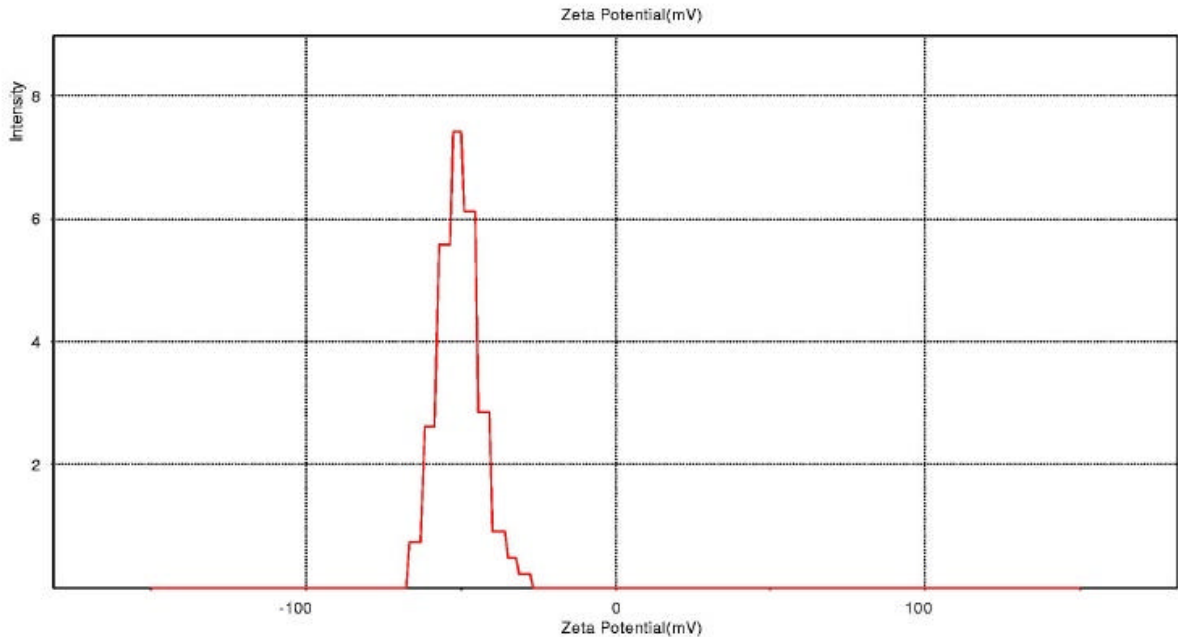
Measuring particle charge (zeta potential)

The charge imparted to particles dispersed in water is called zeta potential. Instruments designed to measure the value of zeta potential do so by subjecting the sample to an electric field and then observing the movement of particles toward an electrode of an electrophoresis cell. The sign of the charge of the particles in the electric field determines direction of movement. A negative charge on the particle causes it to move toward a positive electrode. A positive charge on the particle would cause it to move toward the negative electrode. The velocity of the particle movement is determined by the amount of charge.

The velocity of movement of the particles is measured by evaluating the Doppler shift of scattered laser light. The velocity of particle movement is directly related to its charge. The zeta potential is calculated from the velocity. Zeta potential is expressed in millivolts and usually falls in the range of -70 mV to +70 mV. When the value of the zeta potential is more negative than -30 mV the colloid is considered stable because the particles have sufficient mutual repulsion to provide suspension stability. Zeta potential more positive than -15 mV indicates a suspension at the threshold of agglomeration. Coagulation or flocculation is most rapid when the zeta potential is 0 mV +/- 3 mV.

Zeta potential plot of colloidal silver.

1205-1
 Colloidal silver with no ionic silver.
 fsk
 File data from Live zeta Record 3
 Zetasizer 3000HSData type 1 256



Mean(mV)	Width(mV)	Time	Date	Function	Temp.(°C)	Visc.(cP)	pH	Title
-50.1	1.6	11:53:46	11/12/00	Zeta Pot.	25.0	0.890	7.00	1205-1

Conclusion

Silver colloids must contain suspended particles of silver and usually also contain dissolved silver ions. Solutions that contain only dissolved silver ions are not colloids. High quality colloids contain a high percentage of silver particles. Ideally, a silver colloid would contain no ions.

Silver ions are positively charged and silver particles in colloidal suspension are negatively charged. Reducing ionic silver content causes the zeta potential to become more negative increasing the stability of the colloid.

Colloidal silver products manufacturers would more accurately inform the user by listing on the label what concentration of silver (in parts per million) is contained in the particles. An alternative would be to report what percentage of total silver concentration is contained in the particles and what percent is ionic

About the authors

Francis S. Key is the principle scientist and founder of the Colloidal Science Laboratory which conducts research on metal colloids. Mr. Key was educated at Columbia University and Newark College of Engineering. He has an extensive background in the fields of electrical engineering, computer science, and various branches of physics and engineering. Mr. Key's experience in scientific research and engineering spans a period over 35 years, beginning with his contributions to the design of space flight hardware used on the Apollo and Viking space missions. Mr. Key is known for meticulous attention to details, and relentless investigative procedures, both of which have led to innovative solutions to problems in defense, aerospace and private industry.

Mr. Key has carefully researched the production of colloidal silver, and has built a laboratory facility for colloidal research which is state of the art for the field. He has also instituted analytical methods and developed manufacturing processes which insure the highest purity and consistency possible for a colloidal product. To contact Mr. Key e-mail to: frank@silver-colloids.com

Dr. George Maass - Dr. George Maass holds degrees in chemistry from Fordham University and Iowa State University. For the last 6 years, Dr. Maass has been a professor of chemistry at Camden County College, while operating his own consulting business. He has authored papers and presented seminars on his work in the US, England and Mexico.

Previously to that, Dr. Maass had a successful 25 year career in industry, during which time he applied principles of physics, chemistry, and mathematics to solve diverse industrial problems, invented test methods and developed equations to study structure and fluid behavior in porous materials, and invented and used mathematical models for use in predictive technology, as well as being a consultant in the design of experiments.

A recognized problem solver, he has a strong reputation for the ability to determine the fact which cause phenomena to happen, and to describe the methods by which they can be controlled.

Summary of Properties for Silver

Property	Particles ¹	Atoms	Ions
Increases conductivity of a solution it is added to	N	N	Y
Tyndall Effect	Y	N	N
Can be separated from solution by centrifugation	Y	N	N
Properties will change if an electron is added	N	N	Y
Properties will change if an electron is removed	N	Y	N
Combines readily with anions	N	N	Y
Combines readily with cations	N	N	N
Water soluble	N	N	Y
Exists as a single entity in solution with its peers	Y	N	Y
Measurable with an Ion Selective Electrode	N	N	Y
Measurable by Atomic Absorption Spectrophotometer	Y	Y	Y
Measurable by a Spectrophotometer	N	N	Y
Possesses ionic charge	N	N	Y
May possess particle charge	Y	N	N
Combines with polar molecules	Y	N	Y
Negative zeta potential in low ionic solutions	Y	N	N
Measurable with Photon Correlation Spectrometer	Y	N	N
Can be separated from solution by filtration	Y	N	N
Precipitates from solution onto cathode when an electric current is passed through the solution	N	N	Y

Notes: 1 Particles – in this context, a particle is defined as a cluster of atoms.