# NANOSILVER
# Preparing and investigating colloidal silver

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**Languages available**
English

**Summary**
'Colloidal silver' is a commercially available liquid for which many claims and counter-claims are made about its benefit to health, either by drinking it or applying it to the skin. Its precise composition is unsure, but it appears to be a mixture of silver ions and silver nanoparticles. There is a vast amount of information on colloidal silver.

The Food and Drug Administration (FDA), U.S. Department of Health and Human Services, has issued a Final Rule declaring that all over-the-counter drug products containing colloidal silver or silver salts are not recognised as safe and effective and are misbranded.

So what is the truth? What would an informed balanced article tell its readers about colloidal silver?

**Activity type H**
Use of scientific knowledge and understanding to solve problems
Working in teams to solve problems
Communication
Resource/budget management
Time and workload management

**Techniques**
Synthesis
Aseptic

**Field**
Nanotechnology
Colloid chemistry
Antimicrobial
Microbiology

**Time**

| | |
|---|---|
| Practical lessons: | 480 minutes |
| Theory lessons: | 320 minutes |
| Out of class time: | 340 minutes |

**StandardBase procedures**
None

**StandardBase techniques**
None

**Other resources**
These are listed in the activity.

# Student’s document

## NANOSILVER: Preparing and investigating colloidal silver

When is silver not silver? The answer is when it is colloidal silver, in which case it is yellow. The colour shows the presence of silver nanoparticles that are just tens of nanometres in diameter.

In December 2007, the case of Paul Karason was reported widely in the media. Fourteen years ago, he developed swollen, reddened and itchy skin. He decided to the treat the condition himself using colloidal silver. He drank the liquid and rubbed it into his skin. The effect, however, was that his skin slowly turned blue. And he was not the first case of this type.

‘Colloidal silver’ is a commercially available liquid for which many claims and counter-claims are made about its benefit to health, either by drinking it or applying it to the skin. Its precise composition is unsure, but it appears to be a mixture of silver ions and silver nanoparticles. There is a vast amount of information on colloidal silver. You might start here:
http://en.wikipedia.org/wiki/Colloidal_silver
The Food and Drug Administration (FDA), U.S. Department of Health and Human Services, has issued a Final Rule declaring that all over-the-counter drug products containing colloidal silver or silver salts are not recognised as safe and effective and are misbranded.
http://www.fda.gov/bbs/topics/ANSWERS/ANS00971.html

So what is the truth? What would an informed balanced article tell its readers about colloidal silver?

**Your brief**
Your brief is to produce an article about colloidal silver to be published in a lifestyle magazine. The article should tell the public how effective and safe colloidal silver is (according to your findings from literature searches and experiments).

The stimulus is media reports of the case of Paul Karason. The article must be scientifically accurate, use correct scientific nomenclature and be accessible to non-scientists. It should be about four pages long.

Information about colloidal silver, especially on the Internet, is extensive. You need to search a wide range of secondary sources and make informed decisions about its validity.

You will also be better informed if you carry out some practical work into the preparation and properties of colloidal silver. As often happens in research, a starting point is to try to reproduce experiments carried out by other workers.

You will work in a small team to carry out the necessary literature searches and practical work. The activity is designed to take about 18 hours in total. Organisation and time management is essential to success. You will need to rely on other members of your team, just as they need to be able to rely on you.

**Your investigation**
The investigation consists of a number of tasks that together culminate in the article you need to produce.
The article should include:

- Correct use of scientific terminology related to nanosilver (see task 1)
- An introduction about the potential uses of colloidal silver (see task 2)
- Results you have found to back up claims about the usefulness of colloidal silver (see tasks 3 and 5)
- A brief description of how colloidal silver is made commercially and how the costs involved may affect the widespread use of colloidal silver (see task 4)

***Task 1***
Aim: When writing your article you will need to use terminology you have probably never used before. In this task you will learn the meaning of useful words.

Find out about the nature and language of nanotechnology and colloid chemistry. Obtain a copy of **Information sheet***: Nanoparticles and colloids* to help you. You will need to know the correct scientific language and terminology for your article.

***Task 2***
Aim: Your article will be about potential uses of colloidal silver. In this task you will find out how people have used colloidal silver in the past. This information may form part of the introduction for your article.

Find out about the use of silver, in particular nanosilver and colloidal silver, in medicine. Obtain copies of **Information sheet***: Antibacterial properties of silver* and **Information sheet***: Colloidal silver - claims and counter-claims* to help you. Distil the main points from the information provided and write a brief summary on the use of silver, in particular nanosilver and colloidal silver, in medicine. You will need this background knowledge for your article.

***Task 3***
Aim: To investigate different methods of making colloidal silver and how this affects the stability of the product.

Carry out practical investigations into the chemical synthesis of colloidal silver and the stability of colloidal silver. Obtain a copy of **Information sheet***: Chemical synthesis of colloidal silver* for practical instructions and guidance.

***Task 4***
Aim: Carry out a theoretical investigation into making colloidal silver by electrolytic disintegration. The aim of this task is to determine the costs involved.

You do not actually have to carry out the electrolysis. Obtain a copy of **Information sheet***: Colloidal silver by electrolytic disintegration* for guidance.

***Task 5***
Aim: To test the antibacterial properties of colloidal silver, to try and find evidence to support claims in the literature.

Carry out practical investigations into the antibacterial action of colloidal silver. These might be commercial 'colloidal silver' or samples you made by chemical synthesis or electrolysis. Remember, however, that the chemically-synthesised colloidal silver has other chemicals present. You might also investigate the effect of diluting the colloidal silver you make. Obtain a copy of **Information sheet***: Testing anti-microbial properties of liquids* for practical instructions and guidance.

***Task 6***

Produce an informed article about colloidal silver to be published in a lifestyle magazine. It must be:

- scientifically accurate
- accessible to non-scientists
- use correct scientific nomenclature
- about four pages long

*Planning*

The tasks you need to complete are described above. The team must decide how to use the available time and resources effectively and efficiently.

Once each member of the team has read the brief and associated information sheets, the team should get together and plan how best to use its resources in the time available.

You should allow time for:

- accessing information via the Internet and/or paper-based resources
- carrying out practical work
- team meetings to check progress and share findings (perhaps an initial 30 minute meeting with three further meetings at appropriate times during your work)
- writing the four page article for a lifestyle magazine.

**Your findings**

You should keep a file containing:

- notes summarising the results of your information searches, including annotations that show how you compared information from different sources
- results from practical work, indicating work you did and results that were obtained by other members of your team
- key points from discussions you had with others in your team.

The colloidal silver article should be presented in 'camera-ready' form. This means you need to lay it out as you would wish to see it printed in the magazine. You may, individually or as a team, be asked questions about the article.

**Student self assessment**

This activity is about using scientific knowledge and understanding to solve problems, working in teams to solve problems, communication, time and workload management and resource/budget management. For each case, write 50-100 words explaining:

- what scientific skills and knowledge you used and how effectively you used them
- how you worked as a team, giving examples of how you supported others in your group or were supported by them
- how you managed resources and budgets
- how you managed your time and workload

## Student information sheet: Nanoparticles and colloids

This is an information gathering exercise. You need to gain some background information about nanoparticles and colloids and become familiar with the language used in this branch of science.

You might find it helpful to produce a glossary of terms used in nanotechnology and colloid chemistry.

**What is 'nanotechnology'?**

- Download the activity 5.1 *Nanotechnology size and scale* from http://www.chemsoc.org/networks/LearnNet/inspirational/chapind.htm [Source: Inspirational chemistry, Royal Society of Chemistry 2006, ISBN-10: 0-85404-399-3 and ISBN-13: 978-0-85404-399-6]
- Try the five questions you will find at: http://www.chemsoc.org/networks/learnnet/contemporary/student/nano_intro.html
  and read the three *Did you know* sections.

**What is a colloid?**

- Whipped cream, expanded polystyrene, fog, smoke, milk, jelly, deodorant spray, hair gel … all are examples of colloids.
  Using the terms
  - dispersed phase
  - continuous phase,
  write a definition of a colloid.
- Find out how you can tell if a transparent liquid is a colloid.

## Student information sheet: Antibacterial properties of silver

**An activity to try first …**
Download the activity 5.3 *Nanosilver in medicine* from
http://www.chemsoc.org/networks/LearnNet/inspirational/chapind.htm
and answer the questions.

**Now read more about the use of nanosilver in medical and other applications on the following websites…**

- http://www.agactive.co.uk/information/silvernano/history_of_silver_as_an_antibacterial_agent.cfm
  History of the use of silver as an antibacterial on a commercial website selling silver impregnated socks

- Anti-bacterial silver coatings on orthopaedic metals – an in vitro and animal study, E Sheehan; J McKenna; D Dowling; D McCormack; P Marks; and J M Fitzpatrick, Irish Orthopaedic Association, 19–22 June, 2002
  http://proceedings.jbjs.org.uk/cgi/content/abstract/85-B/SUPP_II/141
  Discussion on the use of silver in an academic paper.

- http://www.decuisine.co.uk/cookshop/kitchen_storage/
  Commercial website selling containers with antibacterial seals made from silver impregnated silicone.

- Slivers of silver solve the problem of smelly socks, Roger Highfield, Science Editor, Last Updated: 7:50pm BST24/06/2003
  http://www.telegraph.co.uk/
  Newspaper article

- http://www.sustainpack.com/news.php?id=63
  European research project looking at sustainable packaging and the uses of silver and gold nanoparticles to give an antibacterial metal/polymer nanocomposite coating.

- http://www.wellcome.ac.uk/
  Scientists in South Africa use nano-silver to create a germ-resistant phone. News item about an antibacterial phone, launched in South Africa in 2005.

- http://www.venturacorporation.co.uk/bodyimpressions/brochure/Body_Impressions_Brochure.pdf
  Commercial website selling products to promote healthy sleep.

- http://www.beggandco.com/admin/downloads/Antimicrobial%20Activity%20of%20Silver-09-05.pdf
  A technical paper on the website of a polymer production company.

- http://www.medicaldevice-network.com/features/feature1330/
  Technical paper on the website of Medical Device Network, a procurement and reference resource.

- http://www.silversox.co.uk/benefits.shtml
  A commercial website selling *Silversox*.

- Standard Soap to help control Hospital Doomsday Bugs (20 June 2006)
  http://www.standardsoap.co.uk/press_release.htm
  Commercial website describing its plan to produce a soap specifically designed to control VRE (Vanocomycin-resistant Enterococci) and MRSA (Methicillin-resistant *Staphylococcus aureus*).

- http://www.physorg.com/news5536.html
  Article about silver nanoparticles helping to fight hospital-related infections.

- http://www.samsung.com/ph/silvernano/
  Commercial website describing how it is using silver as a coating on home appliances.

- A practical procedure for producing silver nanocoated fabric and its antibacterial evaluation for biomedical applications, Hyang Yeon Lee, Hyoung Kun Park, Yoon Mi Lee, Kwan Kim and Seung Bum Park, *Chem. Commun.*, 2007, 2959 – 2961.
  http://www.rsc.org/publishing/journals/CC/article.asp?doi=b703034g
  Article about a new procedure to produce nanosized stable silver particles on cotton fabrics.

- http://www.timesonline.co.uk/
  From The Times, November 29, 2007
  Newspaper article, *The silver lining*, describing silver as a means of reducing bacterial contamination in hospitals, by being included in the making of plastic door handles, handrails and ward furniture.

- http://www.biocote.com/silver.htm
  Commercial website explaining silver technology and the properties of its product, *BioCote*.

## Student information sheet:
## Colloidal silver - claims and counter-claims

**Warning**
The views expressed on the following websites are not necessarily shared by the ProBase team. They must **not** be taken as 'statements of fact'. You may find further information through your own research.

- http://www.coloidalsilver.com/colloidalsilver/colloidal-silver-faq.html
  Commercial website selling colloidal silver.

- http://www.health4youonline.com/health_supplements_flora_sovereign_silver_nim001.htm
  Commercial website selling colloidal silver.

- http://www.dreamweaver.ltd.uk/ElectronicAlchemy/ResLib/How_can_CS_help?.pdf
  Commercial website selling a colloidal silver generator.

- http://www.simplyblessings.co.uk/csg.htm
  Commercial website selling a *Colloidal silver generator*.

- http://www.nutridirect.co.uk/colloidal-silver.html
  Commercial website selling *Colloidal silver*.

- http://www.healthvision2020.com/msg1.htm
  Article on New Zealand health network website.

- http://www.advanced-colloidal-silver.com/
  Commercial website selling *Advanced Colloidal Silver*.

- http://www.silversolution.co.uk/
  Commercial website of supplier of colloidal silver.

- Source: http://www.edirectory.co.uk/pf/880/mia/d/colloidal+silver+spray+100ml+plus+refill+250ml+amazing+antibiotic+alternative/pid/5183343
  Commercial website selling *Colloidal Silver Spray*.

**But what is 'colloidal silver' and how the claims be checked?**
You will find out more when you carry out the practical investigations:
- *Chemical synthesis of colloidal silver*
- *Colloidal silver by electrolytic disintegration*
- *Testing anti-microbial properties of liquids*

## Student information sheet: Chemical synthesis of colloidal silver

*Health and safety*
Wear eye protection. Never look directly into a laser or shine a laser at another person. A risk assessment must be made before the practical work is carried out.

**Synthesising colloidal silver: Method 1**
Based on an article by S.D. Solomon, M. Bahadory, A.V. Jeyarajasingam, S.A. Rutkowsky, C. Boritz and L. Mulfinger (Journal of Chemical Education, 2007, 84, 322)

*Equipment and materials*
- freshly prepared solutions of
- 0.002 mol $dm^{-3}$ sodium borohydride, $NaBH_4(aq)$
- 0.001 mol $dm^{-3}$ silver nitrate, $AgNO_3(aq)$
- glassware that has been cleaned by soaking in an alcoholic potassium hydroxide bath (ethanol; potassium hydroxide)
- laser pen
- ice bath
- magnetic stirrer

*Procedure*
1. Use a measuring cylinder to pour 30 $cm^3$ of sodium borohydride solution into a 250 $cm^3$ conical flask. Place the flask in an ice bath for about 20 minutes, put a magnetic stirring bar in flask and begin the stirring.

2. Add 10 $cm^3$ of silver nitrate solution from a burette at about 1 drop per second. After 2 $cm^3$ has been added, the solution should turn light yellow. Stop stirring when all of the silver nitrate solution has been added. The solution should be a darker yellow.
Colloidal silver will have been produced.

3. Record the appearance of your product as soon as the stirring is stopped and after waiting for about 5 minutes.
Note: Clear yellow colloidal silver will keep for several weeks when stored in a stoppered transparent sample tube (see sample A in photograph below).

4. Shine a laser beam through the product. (You might use a laser pen, the kind normally used during presentations). View the flask from the side and from above. Record your observations and compare them with shining the laser beam through a solution of yellow food dye of similar intensity of colour.

A B C

*Stability of colloidal silver*
In another set of experiments, researchers reported that reaction conditions must be carefully controlled to obtain stable yellow colloidal silver.

- Stirring after the silver nitrate has been added causes aggregation of the silver nanoparticles. The initial yellow product (A) turns a darker yellow (B), then violet (C), and eventually greyish (D). Finally, silver precipitates.
- Varying the concentration of sodium borohydride solution while using the same concentration of silver nitrate solution (0.001 mol $dm^{-3}$) for each experiment, changed the stability of the colloidal silver:

| | | | | |
|---|---|---|---|---|
| Concentration of silver nitrate / mol $dm^{-3}$ | 0.0010 | 0.0010 | 0.0010 | 0.0010 |
| Concentration of sodium borohydride / mol $dm^{-3}$ | 0.0021 | 0.0020 | 0.0019 | 0.0018 |
| Time for breakdown of colloid / minutes | ca 30 | stable | ca 20 | ca 5 |

Carry out a series of experiments to investigate these reported observations.

**Synthesising colloidal silver: Method 2**
From: http://www.mrsec.wisc.edu/Edetc/nanolab/silver/index.html
On the website, the method is described as 'adapted by Steve Ng and Chris Johnson from a procedure developed by S.D. Solomon, M. Bahadory, A.V. Jeyarajasingam, S.A. Rutkowsky, C. Boritz, and L. Mulfinger, Journal of Chemical Education, 84**,** 322-325, (2007)'.

No explanation is given for the modifications. However, method 2 is rather simpler to carry out than method 1. This does illustrate how scientists seek to repeat and where possible improve experimental methods. You will find out whether or not the simplification was effective.

*Materials*

- 0.002 mol $dm^{-3}$ sodium borohydride solution
- 0.001 mol $dm^{-3}$ silver nitrate solution

*Procedure*
1. Using a measuring cylinder, measure out 30 $cm^3$ of freshly prepared 0.002 mol $dm^{-3}$ sodium borohydride solution. Pour the solution into a 100 $cm^3$ conical flask. Add a magnetic stir bar and place the flask in an ice bath on a magnetic stirrer. Stir and cool the liquid for about 20 minutes.

2. Add 2 $cm^3$ of 0.001 mol $dm^{-3}$ silver nitrate solution to the cold, stirred solution at one drop per second. Stop stirring immediately once the silver nitrate solution has been added. Stopper the flask and remove from the ice bath.
Colloidal silver will have been produced.

3. Record the appearance of the product:

- as soon as the stirring is stopped
- 5 minutes after stirring is stopped
- 15 minutes after stirring is stopped
- after it has been left overnight.

4. Shine a laser beam through the product and compare the effect of shining the beam through a solution of yellow food dye with a similar intensity of colour.

*Investigating the importance of reaction conditions in the synthesis*
Repeat the synthesis using these concentrations:

| | | | | | |
|---|---|---|---|---|---|
| Concentration of sodium borohydride / mmol $dm^{-3}$ | 2.2 | 2.1 | 2.0 | 1.9 | 1.8 |
| Concentration of silver nitrate / mmol $dm^{-3}$ | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Time for breakdown / minutes | | | | | |

Record the time taken for the yellow solution to become grey and cloudy.

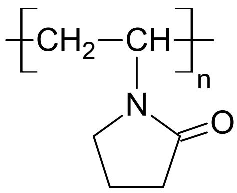
**The stability of colloidal silver**
Depending on how you organised the work within your group, carry out this investigation using the product you made (from either method 1 or method 2).

*Materials*
- Polyvinyl pyrrolidone

*Investigating the effect of adding an electrolyte solution*
*1. Initial trial*
Pour about 2 $cm^3$ of the colloidal silver into a clean test tube. Add 1 drop of 1.5 mol $dm^{-3}$ of sodium chloride solution. Record any changes.

Repeat this, but add 1 drop of 0.3% polyvinyl pyrrolidone (PVP) solution before adding the sodium chloride solution. Record any changes.

Note: Prepare the 0.3% PVP solution by dissolving 0.1 g of polyvinyl pyrrolidone into 33 $cm^3$ of distilled water.



The repeat unit of polyvinyl pyrrolidone

*2. Finding the minimum concentration of polyvinyl pyrrolidone required to stabilise the silver nanoparticles*
Use measuring cylinders to prepare the following PVP solutions starting from the stock 0.3% PVP solution and distilled water:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Volume of 0.3% PVP solution / $cm^3$ | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| Volume of distilled water / $cm^3$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Concentration of PVP solution / % | 0.27 | 0.24 | 0.21 | 0.18 | 0.15 | 0.12 | 0.09 | 0.06 | 0.03 |

If necessary make further dilutions.

## Student information sheet:
## Colloidal silver by electrolytic disintegration

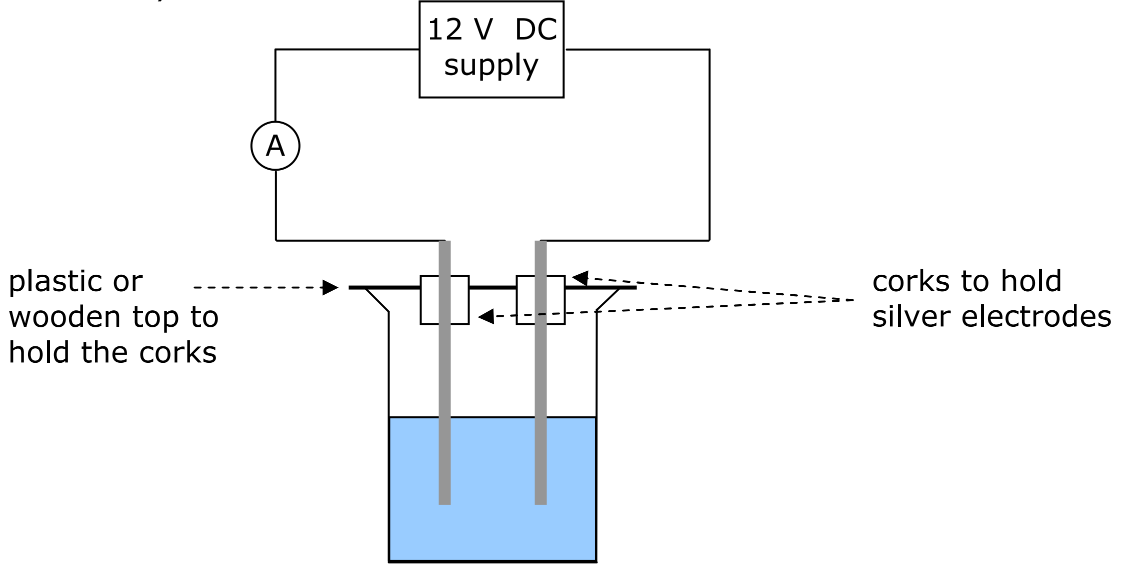
**Making 'colloidal silver' by electrolytic disintegration**
There are many commercial 'generators' available to make colloidal silver by electrolytic disintegration (often called as "electrolysis"). A simple web search will reveal just how many. Also, there are numerous 'do-it-yourself' designs for making colloidal silver by electrolysis.

The outline provided here is based on a method described at http://cancertutor.com/Cancer02/CSilver.html.
We do not recognise this website as an authoritative source of information.
However, the method below was based on this as other methods invariably use higher voltages (30 V is typical).
Some nomenclature and units have been changed.

| **Note** |
| --- |
| You do not need to carry out this experiment.<br>The aim is to see how 'colloidal silver' is made commercially and<br>to compare estimated production costs with typical prices of colloidal silver. |

*Equipment and materials*
- Power supply: A 12 volt D.C. power supply is required with an output of 4-8 A current. The outline method described here is based on a 4 A current. An 8 A current will require less time.
- Silver electrodes: 12 or 14 gauge (AWG) silver wire, between 99.95% and 99.999% pure silver; 14 gauge (1.625 mm in diameter) is said to be preferred. These should be held in corks and connected to the electrical circuit with crocodile clips (or similar).
  http://www.surepure.com/products.php?ID=4&subCat=18&units=Metric
- Electrolysis vessel: A 100 $cm^3$ beaker would be suitable. It must be glass, with a plastic or wooden top. The top should have two holes made to accommodate the corks that support the silver electrodes.
- Storage: Amber jars, stored in the dark, should be used for storing the colloidal silver. The colloid should not be refrigerated.

*The electrolytic unit*



*Carrying out the electrolysis*

1. Half fill the 100 $cm^3$ beaker with distilled water. Warm gently until the temperature is between 50 and 60 $^{O}C$.

2. Put the silver electrodes in place and connect the circuit.

3. Turn the power supply on (12 V DC and a current of 8 A).

4. Every 5 minutes turn off the power, remove the silver electrodes and wipe them with a paper towel and a non-metallic scouring pad. Put the silver electrodes back into the water and turn the power back on.

Notes:

- This is to prevent a black residue crud from building up on the silver wires and sinking to the bottom of the beaker.
- It is important to change the polarity of the silver electrodes every 15 minutes, in other words take turns as the cathode and anode.

5. This process might take 1 to 2 hours (some trial and error is needed). To check that colloidal silver has been produced:

- note the colour of the liquid (yellow indicates colloidal silver)
- shine a laser beam though the liquid.

6. Store the product in an amber jar in a dark cool place, but do not refrigerate.

**Colloidal silver: prices and costs**

You may or may not be able to make a sample of colloidal silver in the laboratory.

However, whether or not you do:

- estimate the cost of making colloidal silver by electrolysis
- look up prices for colloidal silver and compare them with the estimated cost of making it in the laboratory. Explain any differences.

## Student information sheet:
## Testing anti-microbial properties of liquids

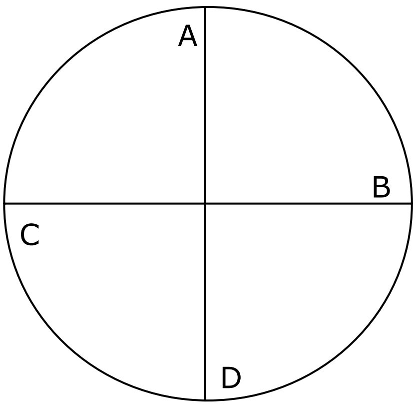
This procedure may be used to test the anti-microbial effects of liquids.
The plate pouring procedure is adapted from British Standard BS 4285-2.1 and similar standards.

A disc of filter paper soaked with the liquid under test is placed on the surface of an inoculated culture plate. After incubation, a clear zone around the disc (called the zone of inhibition) shows the liquid has anti-microbial properties. The liquid has diffused out of the disc and through the agar, preventing the growth of micro-organisms.

**Equipment and materials**
(sterile apparatus)
- Petri dish containing agar seeded with bacteria
- 5 mm diameter discs of filter paper
- forceps
- marker pen to write on Petri dish
- adhesive tape
- incubator set at 30 ± 1 $^{o}$C
- a 'standard' anti-microbial material, e.g. 1% bleach solution (sodium hypochlorite(I) solution)
- the liquid whose anti-microbial properties are to be investigated, for example colloidal silver

**Procedure**
IMPORTANT: Before using this procedure you must be familiar with aseptic techniques, which must be used throughout.
You will be provided with culture plates already prepared.

*Testing*
1. Take the Petri dish containing agar seeded with bacteria and turn it so you can write on the base (containing the agar). Mark out the base with four quadrants (quarter circles) labelled A to D. Turn the dish lid upwards again.




2. Using forceps, dip a 5 mm disc of filter paper into distilled water. Let the surplus liquid drain off. Place the disc onto the surface of the agar in the middle of quadrant D. Gently press it down with the forceps. This is the control specimen.

3. The remaining quadrants may be used for liquids under test. Options include:
   - checking repeatability by soaking each disc with the same liquid
   - comparing the same liquid, but at different dilutions
   - comparing different liquids.

4. Tape down the lid at four points at 90° to each other. (Do not seal it completely, since that would cause anaerobic conditions.)

5. Incubate the dish, with the lid upwards, at 30 ± 1 °C for 48 hours. (Do not turn it lid downwards, or the paper discs may fall off.)

6. After incubation, examine the culture plate without opening it. Measure the zone of inhibition, if any, around each disc. If the zones are all circular, measure their diameters. Otherwise, measure their areas, (for example, by standing the dish on graph paper and counting the squares beneath each zone).

7. When finished with, dispose of the culture plate as instructed by your teacher or supervisor.

**Results**

Record:

- details of the material being tested
- if there is an inhibition zone, its diameter (in millimetres) or its estimated area (in square millimetres)
- comments on the relative anti-microbial action of each specimen.

# Teacher's document

**Overview**
In December 2007, the case of Paul Karason was reported widely in the media. Fourteen years ago, he developed swollen, reddened and itchy skin. He decided to the treat the condition himself using colloidal silver. He drank the liquid and rubbed it into his skin. The effect, however, was that his skin slowly turned blue. His was not the first case of this type.

Using this story as a stimulus, students work in a team of three or four to produce an informed article about colloidal silver for publication in a lifestyle magazine. The article (about four pages) should give an overview of the medical uses of silver. It must be scientifically accurate, use correct scientific nomenclature and be accessible to non-scientists.

To do this, the team must:

- find out about

- the nature and language of nanotechnology and colloid chemistry
- the use of silver, in particular nanosilver and colloidal silver, in medicine;

- carry out practical investigations into

- the chemical synthesis of colloidal silver and the stability of colloidal silver
- making colloidal silver by electrolysis
- the antibacterial action of colloidal silver.

In addition to the article, each student must keep a record of

- notes summarising the results of their literature searches, including annotations that show how they compared information from different sources
- results from practical work, indicating work they did and results that were obtained by other members of their team
- key points from discussions they had with others in their team.

**Developing students' skills**
*Learning objectives*
Students:

- manage relationships to work effectively with others to solve problems
- communicate to an audience of non-scientists effectively
- manage time and workload effectively
- manage resources and budgets effectively
- use scientific knowledge and understanding to solve problems
- observe, measure, analyse and evaluate scientific data.

*Guidance and help*
Students will be expected to have practiced the various skills in other activities. This activity brings the skills together in one exercise. Despite their experience, students will still need guidance and help. It is vital that checkpoints are agreed; these may be set by the teacher or the group.
This activity may allow a variety of assessment criteria to be met, according to the course being followed. Observations of practical work and the completed recording sheets and report should provide evidence that can be judged against published grading criteria.

**Organising and managing the class**
Students work in a group (3-4 would be appropriate). Before embarking upon the activity it is vital that all students understand what the outcome needs to be, i.e. the magazine article, supported by their research notes. This might be a short teacher-led discussion at the start of the first lesson.

Depending on the experience and confidence of the students, it may be appropriate for some to work in a larger group, say 6, to share the workload. Such an arrangement, however, is likely to require careful monitoring.

Before they commence work, ensure that each team knows:

- the time within which they have to work, including how much time they are expected to work on the activity outside of laboratory/classroom time
- when laboratory facilities and resource facilities (e.g. learning resources centre or library) will be available.

Groups should be encouraged to include 'group meetings' when members get together to share results, information and ideas.

Here is a summary of the tasks that comprise the activity.

***Task 1***
Students find out about the nature and language of nanotechnology and colloid chemistry. They are given **Information sheet***: Nanoparticles and colloids* to help them. It is important to stress the purpose of this initial task. The end product of the whole activity is an informed article about colloidal silver for publication in a lifestyle magazine. The article must be scientifically accurate, use correct scientific nomenclature and be accessible to non-scientists. This task enables students to familiarise themselves with the correct scientific language and terminology.

***Answers***
What is 'nanotechnology'?

- Activity 5.1 *Nanotechnology size and scale*

| **Name** | **Symbol** | **Numerals** | **Image** |
|---|---|---|---|
| terametre | Tm | $10^{12}$ m | bigger than the diameter of the solar system, less than the distance to the closest star |
| gigametre | Gm | $10^{9}$ m | the Sun is 1.5 Gm across |
| megametre | Mm | $10^{6}$ m | Earth |
| kilometre | km | $10^{3}$ m | Angel Falls, Venezuela – 980 metres |
| hectometre | hm | $10^{2}$ m | football pitch |
| decametre | dm | 10 m | Orca (or Killer Whale) |
| metre | m | 1 m | Royal Python snake |
| centimetre | cm | $10^{-2}$ m | width of a fingernail |
| millimetre | mm | $10^{-3}$ m | mite |
| micrometre | µm | $10^{-6}$ m | bacterium |
| nanometre | nm | $10^{-9}$ m | Buckyball (Buckminsterfullerene) – approximately 1 nm |
| picometre | pm | $10^{-12}$ m | atom diameters range from 30–600 pm |

- Students try the five questions at:
  http://www.chemsoc.org/networks/learnnet/contemporary/student/nano_intro.html
  and read the three *Did you know* sections.

What is a colloid?
- A colloid is a mixture. It consists of tiny particles of one substance (the dispersed phase) dispersed in another substance. The two substances do not separate easily and, under the correct conditions, will remain mixed indefinitely.
- The tiny suspended particles scatter light. A red laser beam remains invisible as it passes through a true solution. However, the path of the beam can be seen in a colloid because of scattering caused by the dispersed phase particles.

***Task 2***
Students find out about the use of silver, in particular nanosilver and colloidal silver, in medicine. They are given **Information sheet***: Antibacterial properties of silver* and **Information sheet***: Colloidal silver - claims and counter-claims* to help them. The two information sheets contain a large number of web references. It will save time if the relevant sites are collected in a file so that students can readily access the information. Alternatively, the relevant pages could be printed out for the students.

Emphasise to students that most of the material on the websites has not been peer-reviewed and must not be taken as scientifically accepted or accurate.

It is likely to take students considerable time to read through and highlight key points. They need to be encouraged to look for consistent comments, ambiguities and inconsistencies. The purpose is to give a balanced summary of the claims for silver, especially in medical applications. The evidence for its antibacterial action is overwhelming, but some other claims are not supported by reputable scientific evidence and are dubious.

Another issue that may arise is the form of silver. Students will find out that commercial colloidal silver, made by electrolysis, is a mixture of silver nanoparticles ($Ag^{O}$) and silver ions ($Ag^{+}$). It appears to be the silver ions that are active. However, silver nanoparticles appear to be useful because they provide a slow release of silver ions.

One UK provider says it product contains 80% $Ag^{+}$ and 20% $Ag^{O}$ (particle size in the range 0.001 - 0.040 μm), at a concentration of 10 parts per million (ppm). Further, they say, “We believe both types of silver are very important and the combination solution we produce is the logical approach. We refuse to be drawn into a debate between the two, which I am sure are just marketing ploys used by some sites to differentiate their products from others. We do not recommend or manufacture Mild Silver Proteins (MSP) as the high silver content can lead to undesirable side effects.”

Answers (from the Royal Society of Chemistry resource)

1. The properties of silver that make it useful for jewellery are: it is unreactive, shiny and does not dissolve in water.

2. These properties would make silver less useful for medicine because if it does not dissolve it will be hard to get it into the body and if it is unreactive it will not do anything even if it does get to the source of the problem.

3. The SILCRYST® nanocrystals on the Acticoat® dressings are much smaller than the normal crystals and their surface is much rougher. This means they have a much larger surface area than the normal crystals.

4. This will make the silver more reactive as it is the atoms at the surface that are able to react or dissolve. As there are far more atoms at the surface of the nanosilver it is much more reactive than normal silver.

5. The bacteria will multiply very rapidly if they are not killed. The conditions in a wound are close to optimum for bacteria and they could double in number every 20 minutes, which would quickly lead to an infection. The infection could then spread elsewhere in the body.

6. The nanoparticles are more effective against the bacteria as they dissolve far more quickly than larger particles. Nanosilver can therefore get to work faster than normal silver.

7. If dressings are improved, this may mean that fewer people get infections that could become serious and make them very ill or lead to an amputation. Improving simple treatments could help reduce the need for more difficult ones.

***Task 3***
Students synthesise colloidal silver by a chemical reduction. They investigate the stability of colloidal silver.

***Task 4***
Students investigate the preparation of colloidal silver by electrolysis. They may be able to carry out the preparation, but this is not essential. The main purpose of this task is for students to look at the cost of a chemical process and compare it with the prices if commercial products.

Websites for methods to make colloidal silver by electrolysis:
http://www.elixa.com/silver/lindmn.htm
http://www.uk-cs.co.uk/home2.htm
http://chetday.com/colloidalsilvergenerator.htm
http://chetday.com/colloidalsilvergenerator2.htm
http://www.silvermedicine.org/production.html
http://www.emanator.demon.co.uk/bigclive/silver.htm
http://keelynet.com/biology/colloid.htm
http://standeyo.com/News_Files/INFO_Files/Colloidal_Silver.html
http://www.lwpub.com/downloads/CS_archives/CS3_plans.html
http://www.lwpub.com/downloads/CS_archives/make_silver_generator3.htm
http://cancertutor.com/Cancer02/CSilver.html

Sources of commercial colloidal silver:
http://www.uk-cs.co.uk/home2.htm

Typical price (including delivery):
500 cm$^3$ of 10 ppm colloidal silver (80% $Ag^+$ and 20% $Ag^O$)
UK £19.95; EU £21.95
http://www.caninenaturalcures.co.uk/silver.htm
https://www.thehealthy-shopper.com/?main_page=product_info&cPath=9&products_id=29
http://www.aguasilver.com/paypal/Colloidal_Silver.html

A simple Internet search will reveal other suppliers.

**IMPORTANT**
**The use of colloidal silver is NOT being advocated.**
**There are contrasting views about the medical value of colloidal silver.**
**No decision to use colloidal silver should be taken without adequate research concerning its properties and advice from reputable sources.**

***Task 5***
Students carry out practical investigations into the antibacterial action of colloidal silver. This might be commercial colloidal silver or samples they have synthesised, either chemically or by electrolysis.

***Task 6***
Students produce an informed article about colloidal silver to be published in a lifestyle magazine. It must be scientifically accurate, use correct scientific nomenclature, be accessible to non-scientists and about four pages long.
In order that they can plan their work, students should be told the times when they can access various facilities, e.g. laboratory, IT facilities, study centres. They will need to organise their work around these times.

**Session plan for teachers**
Exact timing depends on many factors, but the following is suggested:
- Introduction and checking prior knowledge (30 minutes)
- Initial planning meeting for students (30 minutes)
- Allow time for at least three checks during the 18 hours (90 minutes)
- Task 1 (30 minutes)
- Task 2 (140 minutes)
- Task 3 (240 minutes)
- Task 4 (140 minutes)
- Task 5 (240 minutes)
- Task 6 (200 minutes)

## Technical notes

### *Task 3*
Practical investigations into the chemical synthesis of colloidal silver and the stability of colloidal silver (**Information sheet***: Chemical synthesis of colloidal silver*)

**Preparation**

- 0.0010 mol dm$^{-3}$ $AgNO_3$
  Add 0.0170 g silver nitrate to a 100 cm$^3$ volumetric flask and dilute to the mark with distilled water
- 0.0020 mol dm$^{-3}$ $NaBH_4$ (aq)
  Add 0.0189 g sodium borohydride to a 250 cm$^3$ volumetric flask and dilute to the mark with distilled water. Note: Although more expensive, it is advisable to use '99.995% sodium borohydride' rather than '99% sodium borohydride'. The purer form is more reliable as aggregation can occur if the sodium borohydride is slightly less than 99% (and some batches may be).
- 0.3 g/100 cm$^3$ PVP ($M_r$ = 10 000)
  Dissolve 0.1 g of PVP into 33 cm$^3$ distilled water.
- Alcoholic potassium hydroxide solution for cleaning glassware
  Add 120 cm$^3$ of water to 1 dm$^3$ of 95% ethanol. Dissolve 120 g potassium hydroxide in the mixture. Note: The possibility of aggregation increases if the glassware is not thoroughly clean.

**Equipment and materials**

*Materials and their CAS numbers*

| | | |
|---|---|---|
| Method 1 | | |
| 0.002 mol dm$^{-3}$ sodium borohydride | $NaBH_4$(aq) | 16940-66-2 |
| 0.001 mol dm$^{-3}$ silver nitrate | $AgNO_3$(aq) | 7761-88-8 |
| | | |
| Method 2 | | |
| 0.002 mol dm$^{-3}$ sodium borohydride solution | | 16940-66-2 |
| 0.001 mol dm$^{-3}$ silver nitrate solution | | 7761-88-8 |
| | | |
| The stability of colloidal silver | | |
| Polyvinyl pyrrolidone | | 9003-39-8 |
| 1.5 mol dm$^{-3}$ sodium chloride solution | | 7647-14-5 |

*Equipment*

- eye protection
- glassware cleaned by soaking in an alcoholic potassium hydroxide
- magnetic stirrer
- laser pen

### *Task 4*
Practical investigations into making colloidal silver by electrolysis (**Information sheet***: Colloidal silver by electrolytic disintegration*)

**Equipment and materials**

- Griffin offers a range of power supplies. See
  http://www.catalogue.fisher.co.uk/pdf/411grif.pdf
  EKR-683-010T would be suitable.

- silver electrodes: 12 or 14 gauge (AWG) silver wire, between 99.95% and 99.999% pure silver; 14 gauge (1.625 mm in diameter) is said to be preferred. ‘Surepure Chemetals’ is one supplier: http://www.surepure.com/products.php?ID=4&subCat=18&units=Metric

To save time, the electrolysis cell might be assembled in advance.

- electrolysis vessel: A 100 $cm^3$ beaker would be suitable. It must be glass, with a plastic or wooden top. The top should have two holes made to accommodate the corks that support the silver electrodes.
- amber jars

***Task 5***

Practical investigations into the antibacterial action of colloidal silver (**Information sheet***: Testing anti-microbial properties of liquids*).

You may not have the background or experience to supervise this task. If necessary work with a colleague who has experience of aseptic technique. Good sources of advice and guidance, including health and safety:

- The Microbiology in Schools Advisory Committee http://www.microbiologyonline.org.uk/misac.html

- National Centre for Biotechnology Education http://www.ncbe.reading.ac.uk/

In both cases, the advice is applicable to UK schools and colleges. If you are working in another country, you will need to find an equivalent source of information.

- You may find this US website helpful: http://www.microeguide.com/TOC_Safe_frame.htm

**Preparation**

Culture plates should be prepared in advance, using sterile apparatus, by a teacher or technician experienced in aseptic technique. This could be done 30 minutes to an hour before the lesson (bottle containing 20 $cm^3$ of molten nutrient agar suitable for micro-organism being tested; Petri dish; dropping pipette).

1. Keep the molten agar at 45 to 47 $^{O}C$ until you are ready to use it.

2. Place the sterile Petri dish on the bench, lid upwards.

3. Using the sterile dropper, put 5 drops of bacterial culture into the dish. Add the 20 $cm^3$ of molten agar. Replace the lid.

4. Immediately mix the contents by gently sliding the dish over the bench with the following movements:

- five times from side to side
- five times in a clockwise circle
- five times back and forth (at $90^{O}$ to the side to side movements)
- five times in an anticlockwise circle.

5. Leave the plate to set.

Alternatively, if you would like your students to prepare the plates, you will need to print out the instructions above.

**Equipment and materials**

- Petri dish containing agar seeded with bacteria
- 5 mm diameter discs of filter paper
- forceps
- marker pen to write on Petri dish
- adhesive tape
- incubator set at 30 ± 1 $^{o}$C
- a 'standard' anti-microbial material, e.g. 1% bleach solution (sodium hypochlorite(I) solution)
- the liquid whose anti-microbial properties are to be investigated, for example colloidal silver

On the next page are some general guidance notes on aseptic technique (**Information sheet***: Aseptic technique*). You may wish to give copies to the students.

## Information sheet: Aseptic technique

Aseptic technique is the most important skill a microbiologist needs to learn. Using aseptic technique makes it unlikely that samples are contaminated with micro-organisms from the environment (in the air or on surfaces) and the micro-organisms being studied do not escape to cause infection.

**Basic guidelines**

- Wear gloves and a clean laboratory coat (one which stays in the laboratory).
- Before beginning work, make sure your work place is clean (use an appropriate disinfectant spray or wipe over surfaces using a suitable disinfectant cleaner).
- Work quickly but carefully to reduce the time specimens are open/out of incubators.
- Avoid working in draughts or next to open windows, where micro-organisms may blow across your work place.

**Aseptic technique**

- Sterilise equipment in an autoclave before use or use disposable sterile equipment.
- Once removed from its packet, avoid contaminating sterile equipment (for example, do not put down on the laboratory bench or walk around the room with it).
- If sterile equipment accidentally touches a non-sterile surface (such as the outside of a bottle) discard it and start again with a sterile item.
- When removing caps and lids from containers they should not be placed on the workbench, but retained in the hand whilst the sample is being processed, taking care not to contaminate the hand or cap. If possible, hold the lid the right way up. Caps and lids should be replaced as soon as possible.
- If the work is being carried out on the open bench, a Bunsen burner should be in close proximity to flame loops, wires or bottle necks.
- When opening culture containers, keep samples away from the face.

**Airborne contamination should be minimised as follows:**

- Open caps slowly as the contents are sometimes under pressure.
- Avoid vigorous swirling or shaking of the sample prior to opening.
- Cool loops that have been heated before use (to prevent spluttering).
- Avoid expelling the last drop from a pipette.
- If forceps or scissors are used when handling specimens, they should be heated in a Bunsen flame and allowed to cool before use.
- Loops and wires should be heated in the Bunsen flame with the loop end downwards until red-hot, then removed and allowed to cool. Care should be taken to see that the loop does not contain fluid or large particles of matter that may ‘splutter’ when placed into the flame, and that the entire loop and wire up to the loop holder is heated to red-heat.
- Petri dish lids should only be removed when necessary and for the minimum time only. Lids should be held over the dish during transfer operations.

**Disposal**

Treat all cultures as potentially pathogenic. All waste that has come into contact with micro-organisms should be classed as a biological hazard. It will need to be sterilised before disposal. Follow your laboratory guidelines for disposal.

## Testing prior knowledge

1. Which of the following pairs of statements is true?
a. oxidation is gain of oxygen; reduction is gain of oxygen
b. oxidation is gain of oxygen; reduction is the gain of electrons
c. oxidation is the gain of electrons; reduction is gain of oxygen
d. oxidation is the gain of electrons; reduction is the gain of electrons

2. Look at the following redox reactions:

A $CuO + H_2 \rightarrow Cu + H_2O$
B $2Cu^{2+} + 4I^- \rightarrow 2CuI + I_2$
C $Cu^{2+} + Zn \rightarrow Cu + Zn^{2+}$
D $Cu + 2Ag^+ \rightarrow Cu^{2+} + 2Ag$

Match the following statements to the reactions

| | |
|---|---|
| a. Zinc is oxidised | C |
| b. Copper is oxidised | D |
| c. Copper is reduced | B |
| d. Hydrogen is oxidised | A |

3. Which of the following statements about electrolysis is false?
a. The cathode is positive FALSE
b. Anions are negative
c. Anions lose electrons during electrolysis
d. Cations gain electrons during electrolysis

4. Water is a poor conductor of electricity.
a. Write an equation for the electrolysis of water.
$2H_2O \rightarrow 2H_2 + O_2$
b. Write the two half reactions, using $e^-$ to represent electrons, and state which is oxidation and which is reduction.
$2H^+ + 2e^- \rightarrow H_2$ (reduction); $4OH^- \rightarrow O_2 + H_2O + 2e^-$ (oxidation)

5. Silver ions may be reduced to silver atoms by sodium borohydride:
$2AgNO_3 + 2NaBH_4 \rightarrow 2Ag + H_2 + B_2H_6 + 2NaNO_3$
a. In what mole ratio do silver nitrate and sodium borohydride react?
1:1
b. Write an ionic equation for the reaction.
$2Ag^+ + 2BH_4^- \rightarrow 2Ag + H_2 + B_2H_6$
c. Write the two half reactions, using $e^-$ to represent electrons, and state which is oxidation and which is reduction.
$2Ag^+ + 2e^- \rightarrow 2Ag$ (reduction); $2BH_4^- \rightarrow H_2 + B_2H_6 + 2e^-$ (oxidation)
d. What are the 'spectator ions' in the reaction (i.e. ions that take no part in the reaction)?
sodium ions, $Na^+$, and nitrate ions, $NO_3^-$

Note:
Answers are given in red. These need to be deleted before the test is used.

## Testing prior knowledge

1. Which of the following pairs of statements is true?
a. oxidation is gain of oxygen; reduction is gain of oxygen
b. oxidation is gain of oxygen; reduction is the gain of electrons
c. oxidation is the gain of electrons; reduction is gain of oxygen
d. oxidation is the gain of electrons; reduction is the gain of electrons

2. Look at the following redox reactions:
A $CuO + H_2 \rightarrow Cu + H_2O$
B $2Cu^{2+} + 4I^- \rightarrow 2CuI + I_2$
C $Cu^{2+} + Zn \rightarrow Cu + Zn^{2+}$
D $Cu + 2Ag^+ \rightarrow Cu^{2+} + 2Ag$

Match the following statements to the reactions
a. Zinc is oxidised
b. Copper is oxidised
c. Copper is reduced
d. Hydrogen is oxidised

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4. Water is a poor conductor of electricity.
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5. Silver ions may be reduced to silver atoms by sodium borohydride:
$2AgNO_3 + 2NaBH_4 \rightarrow 2Ag + H_2 + B_2H_6 + 2NaNO_3$
a. In what mole ratio do silver nitrate and sodium borohydride react?
b. Write an ionic equation for the reaction.
c. Write the two half reactions, using $e^-$ to represent electrons, and state which is oxidation and which is reduction.
d. What are the ‘spectator ions’ in the reaction (i.e. ions that take no part in the reaction)?