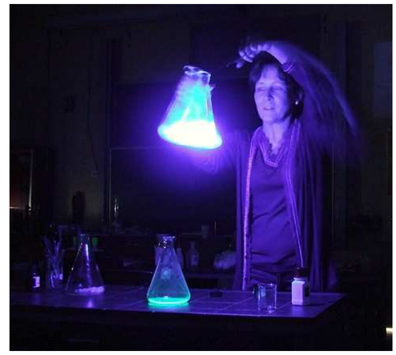
COLD LIGHT
Investigating analyses using chemiluminescence



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Languages available
English, Slovenian

Summary
Students take the role of analytical scientists working in an environmental laboratory. An important part of the laboratory's work is analysis of water, in particular the determination of very low metal ions concentrations in water. Their manager has heard about the use of chemiluminescence as an analytical technique. She has asked the analytical team to find out more about chemiluminescence and its potential use in analysis. She wants the team to carry out some initial research, write a brief report on it and propose a costed research programme to investigate more fully the potential of luminol chemiluminescence in metal ions analysis.

Activity type G
Use of scientific knowledge and understanding to solve problems
Working in teams to solve problems
Communication
Resource/ budget management

Techniques
Chemiluminescence

Field
Analysis

Time
Practical lessons: 260 minutes
Theory lessons: 180 minutes
Out of class time: 160 minutes

StandardBase procedures
None

StandardBase techniques
None

Other resources
Zavod za šolstvo, Ljubljana (The National Education Institute of the Republic of Slovenia); http://www.zrss.si/
http://en.wikipedia.org/wiki/Luminescence
http://en.wikipedia.org/wiki/Chemiluminescence
http://www.shsu.edu/~chemistry/chemiluminescence/CLUMIN.html
http://www.practicalchemistry.org/experiments/chemiluminescence-cold-light,62,EX.html
http://www.shsu.edu/~chm_tgc/JPPdir/JPP1999/
http://qsad.bu.edu/curriculum/labs/Luminol3_1.html
http://www.glowspace.com/classroom.htm
http://www.chm.bris.ac.uk/webprojects2002/fleming/experimental.htm
http://www.lumigen.com/documents/chemexplained.shtml
http://www.lumigen.com/documents/assays.shtml
http://www.lumigen.com/documents/clinapps.shtml

Student's document

COLD LIGHT: Investigating analyses using chemiluminescence

Luminescence is light produced without the need for heat, unlike the light from a candle flame or a filament light bulb. It is sometimes called 'cold light'. One form of luminescence is chemiluminescence. It comes from chemical reactions that release energy not in the form of heat (exothermic reactions), but in the form of light energy. Analysis using chemiluminescence is an emerging analytical technique with a range of applications.

Your brief

You are an analytical scientist working in an environmental laboratory. An important part of the laboratory's work is analysis of water, in particular the determination of very low metal ions concentrations in water.

Your manager attended a research seminar recently. She heard about the use of chemiluminescence as an analytical technique. She was particularly interested in one presentation by a university researcher who outlined the potential advantages of chemiluminescence over conventional techniques. He said, "*Chemiluminescence takes its place among other spectroscopic techniques because of its inherent sensitivity and selectivity. It requires no excitation source (as does fluorescence and phosphorescence), only a single light detector such as a photomultiplier tube and no monochromator and often not even a filter. Although not as widely applicable as excitation spectroscopy, the detection limits for chemiluminescent methods can be 10 to 100 times lower than other luminescence techniques.*" The researcher outlined a simple system that used a substance called luminol. Amongst its analytical applications was the determination of concentrations of metal ions.

Your manager has asked the analytical team to find out more about chemiluminescence and its potential use in analysis. She wants you to do some initial research, write a brief report on it and propose a costed research programme to investigate more fully the potential of luminol chemiluminescence in metal ions analysis.

You need to show that, working in a team, you can (a) communicate effectively, (b) manage resources and budgets. How you set about the work depends on the size of the team you have been assigned to for this project.

Your investigation

Plan and prepare

To meet your brief, there are several tasks to carry out. Before starting, each member of the team should read through the tasks and supporting information carefully. Your manager will assign a series of tasks to each team member.

Practical activity

A risk assessment must be carried out before starting practical work.

Task 1: Changes that produce 'cold light' (luminescence)

Carry out some initial investigations into luminescence using these two resources:

- *Inspirational chemistry - resources for modern curricula*: *7.4 Cold light*. Go to http://www.chemsoc.org/networks/learnnet/inspirational/ for instructions. If you are unable to get the instructions, your teacher will provide them.
- **Student sheet***: Oxidation of luminol by sodium chlorate(I)*
  Record all observations and measurements in your laboratory notebook. You may try using a light meter to measure the intensity of the light produced. Also, find out about and explain the difference between fluorescence and chemiluminescence in terms of how cold light is produced.

Task 2: The catalytic oxidation of luminol
The aim of this task is to carry out a series of exploratory investigations into the possible use of chemiluminescence as an analytical technique to determine the concentration of metal ions in solution.

The catalytic oxidation of alkaline solutions of luminol by hydrogen peroxide produces chemiluminescence. A number of metal ions are effective catalysts.

Use **Datasheet***: Oxidation of luminol using hydrogen peroxide* to plan experiments that will enable you to assess the potential of the catalytic oxidation of luminol by hydrogen peroxide for the analysis of metal ions in solution.

You are not likely to obtain quantitative data. However, this is not important. The purpose of the task is to observe whether or not the brightness and duration of any chemiluminescence appears to be affected by the concentration of metal ion catalysts. You need to gather sufficient evidence to propose a more detailed, quantitative study (Task 3).

Work in pairs within your team and assign one of these metal ions to each pair to investigate:
- hexaaquacopper(II), $[Cu(H_2O)_6]^{2+}$
- hexaaquacobalt(II), $[Co(H_2O)_6]^{2+}$
- hexacyanoferrate(III), $[Fe(CN)_6]^{3-}$

You might try using a light meter to compare the intensity of the light produced in different reactions. If so, follow the instructions that come with the meter. It is likely that you will need to work in a darkened room.

Task 3: Proposal for a detailed study
On the basis of the team's investigation, write a costed proposal for a detailed study of the analytical potential of chemiluminescence. Each member should do this for <u>one</u> of the three metal ions that the team investigated.
You need to:
- describe the series of experiments to be carried out, with reasons for the choice
- estimate the cost of the detailed study by considering

\- the price of consumables (chemicals) using chemical suppliers' catalogues
\- approximately how long the experiments will take (take the cost of a chemist's time as £40 per hour, which includes salary and associated costs, building, environmental and other overheads).

Note: If you do not live in the UK, use salaries and overhead costs typical for your own country.

You may find it useful to summarise your plans and data for the costed proposal using **Datasheet***: Data to support costed detailed investigation proposal*

Your findings
Record:
- the results of your initial investigation into cold light and what you found out about the difference between fluorescence and chemiluminescence
- the results of your exploratory investigation into the catalysed oxidation of luminol by hydrogen peroxide.

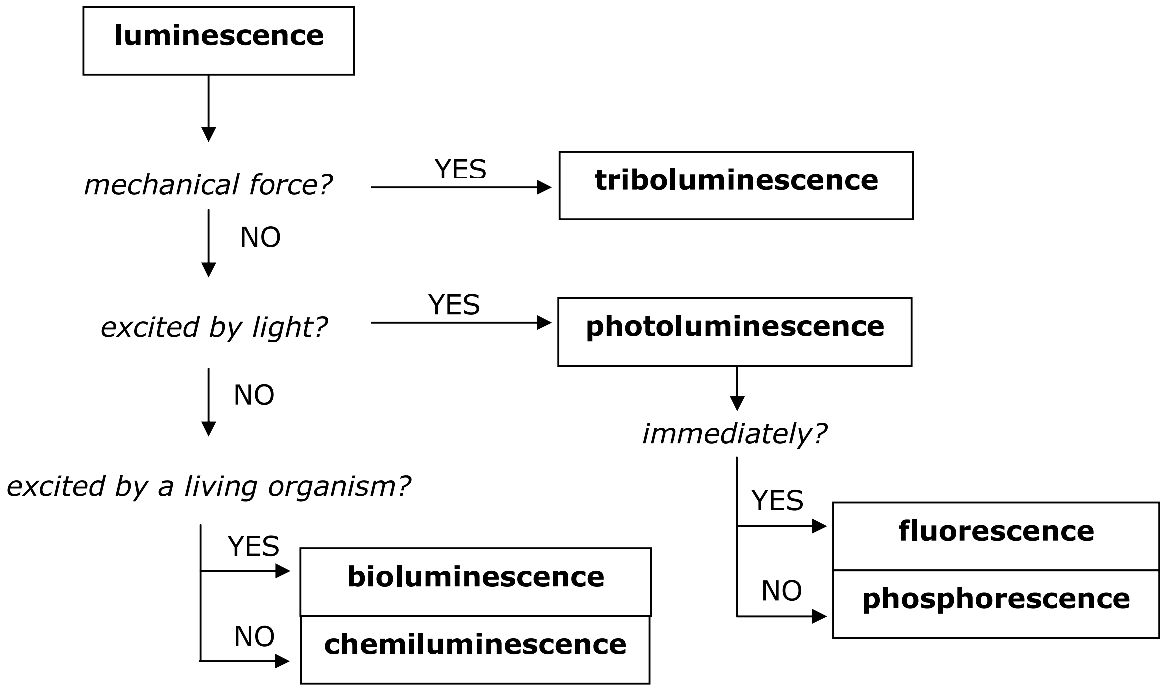
Write a costed proposal, based on your exploratory investigations, for a more detailed study.

Student self assessment
This activity is about using scientific knowledge and understanding to solve problems, working in teams to solve problems, communication and managing resources and budgets. For each case, write about 50-100 words explaining:
- what scientific skills and knowledge you used and how effectively you used them
- how you worked as a pair, giving examples of how you supported one another, and, if appropriate, worked with another pair
- what you learned about managing resources and budgets
- what you learned about communication

Student sheet: Cold light

Based on *Inspirational chemistry- resources for modern curricula*: *7.4 Cold light*.
http://www.chemsoc.org/networks/learnnet/inspirational/

Cold light (luminescence) is light that is emitted when things are cold. There are many types, given different names depending on the conditions under which the light is emitted. The flow chart below shows how you can decide which type of light an object is emitting.



Health and safety

- Do not look at the UV light; always have it pointing away from your eyes and shine it only on the items you are observing.
- Ethanol is flammable – do not use it near flames.
- When using the pliers take care not to crush your fingers.
- Do not eat anything in a laboratory.
- Wear eye protection.

What to do

Set up a table like the one below for your observations.

Item	White light		UV light		Luminescent	Type of luminescence
	on	off	on	off		

1. Cut up the spinach into very small pieces. Wearing eye protection, scrape these into the beaker and just cover them with ethanol. With the beaker on the bench, gently press on the spinach leaves with the glass rod. When the leaves are looking pale and the ethanol is very green, carefully decant the ethanol into the boiling tube and put a bung into it.

2. Using the fluorescent pens, write or colour on the brown paper.

3. In a darkened room, shine a white light on each of the items in turn. Look carefully at the items and note the colour and intensity (bright, dim etc) of any light given off by them. Make sure you observe the spinach extract in the boiling tube from several angles and note any differences.

4. Turn off the light and make the same observations.

5. Repeat the above using UV light.

6. Leave the boiled sweet in its wrapper and place it inside the plastic bag. Make sure that the area where you are working is dark and then crush the sweet using the pliers. Watch the sweet carefully as you crush it.

7. Decide if each item is luminescent and what type of luminescence it shows.

Note for non-UK students
Boiled sweets are hard sweets (made of crystallised sugar). The image below shows an example:

Brown paper is paper that is coloured brown. It is usually used for wrapping parcels. The image below shows an example of a parcel wrapped in brown paper:

Student sheet: Oxidation of luminol by sodium chlorate(I)

This procedure is based on one from the *Practical Chemistry* website:
http://www.practicalchemistry.org/experiments/chemiluminescence-cold-light,62,EX.html

Make fresh stock solutions on the day you plan to use them, if they have not already been prepared for you. You will need these solutions:

- Sodium chlorate(I) solution, about 0.08 mol dm^{-3} (solution **A**)
  Add 50 cm^3 of 13% sodium chlorate(I) solution to 950 cm^3 of distilled water in a flask, mix well and stopper.
- Alkaline luminol solution, about 0.002 mol dm^{-3} (solution **B**)
  Put 0.4 g of luminol into a flask containing 4.0 g of sodium hydroxide dissolved in 1 dm^3 of distilled water. Swirl to dissolve the chemicals and then stopper the flask. The luminol does not always appear to dissolve completely, leaving a fine, greenish suspension.

Note: In each case the total volume of each may be scaled up or down.

Procedure

1. Record the temperatures of solution **A** and solution **B**.
2. Lower the room lights and slowly pour 10 cm^3 of each solution simultaneously at the same rate into a boiling tube. Gently shake the tube so that the solutions mix.
3. Record your observations:

- colour/intensity of light produced
- how long it persists
- the temperature of the mixture immediately after mixing and again when the light begins to disappear (it is best to use a fast-response thermometer).

Variations

Plan a series of experiments in which you investigate changing the following:
The concentration of:

- the sodium chlorate(I) solution
- luminol in the alkaline luminol solution
- sodium hydroxide in the alkaline luminol solution.

The temperature of the solutions A and B:

- store solutions in an ice bath and mix them in a boiling tube stood in the ice bath
- store solutions in a water bath at 40 ^{o}C and mix them in a boiling tube standing in the water bath
- store solutions in a water bath at 60 ^{o}C and mix them in a boiling tube standing in the water bath

In each case, compare the intensity of the light produced and the time it persists.

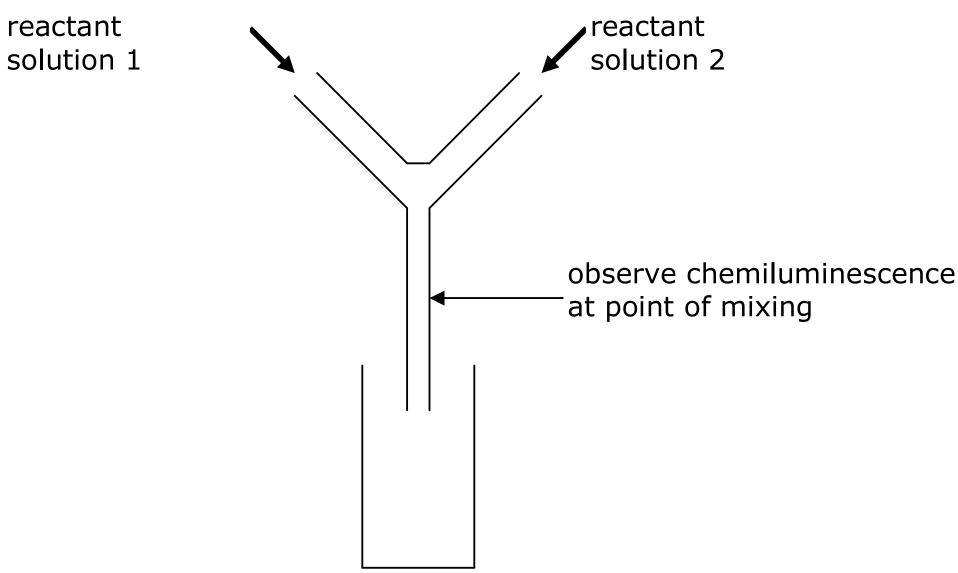
Student datasheet: Oxidation of luminol using hydrogen peroxide

Luminol may be oxidised by hydrogen peroxide in the presence of a suitable catalyst. Catalysts include some metal ions.

The methods given below are based on ones from a number of sources. You may be able to find others.

Notes:

- Some methods may appear very similar. This might suggest to you that they are reliable and worth adapting for your investigation.
- The quantities are those given in the references. Occasionally names and units have been changed according to IUPAC recommendations. To be able to compare methods you may need to convert the units given in one to those used in another.
- You are likely to find that the chemiluminescence is initially very bright, but fades very quickly. This may make it difficult to compare two or more reactions. Consider this idea to make comparisons:
  Slowly pour the two solutions into separate sides of a Y-tube. As they mix, the chemiluminescence is at its brightest. The continuous mixing of reactants will help to prolong this effect.



Catalyst: Cu^{2+}

http://www.shsu.edu/~chm_tgc/JPPdir/JPP1999/

- Luminol solution:

- 1×10^{-3} mol dm^{-3} luminol
- 0.05 mol dm^{-3} sodium carbonate
- 0.3 mol dm^{-3} sodium hydrogencarbonate
- 5×10^{-3} mol dm^{-3} ammonium carbonate
- 1.5×10^{-3} mol dm^{-3} Cu(II) (added as sulfate salt)

- Hydrogen peroxide solution: approximately 0.25%

Approximately 15 cm^3 of the luminol solution is measured into a flat-bottom sample tube and the hydrogen peroxide solution is added drop by drop.

http://qsad.bu.edu/curriculum/labs/Luminol3_1.html

- Luminol solution:

Pour 50 cm^3 of distilled water into a 1 dm^3 conical flask. Carefully add:
- 4.0 g sodium carbonate
- 0.2 g luminol
- 24.0 g sodium hydrogencarbonate
- 0.5 g ammonium carbonate monohydrate
- 0.4 g copper(II) sulfate-5-water

Mix to dissolve the solids (using a magnetic stirrer will help the luminol to dissolve completely). Fill the flask to 1 dm^3 with distilled water and mix. The final solution should have a pH of 9. Test the solution with pH paper, and if its pH is below 9, add a small amount of ammonium carbonate monohydrate to increase the pH.

- Hydrogen peroxide solution:

Pour 50 cm^3 of 3% hydrogen peroxide to a 1 dm^3 conical flask. Fill to 1 dm^3 with distilled water and mix. Final solution is approximately 0.15%.

Use a glass spiral assembly. Place a funnel at the top of the spiral. Place a 2 dm^3 flask under the spiral to collect the solution. Pour about 100 cm^3 of water through the spiral assembly to gauge the flow rate. Discard the water collected in the flask. Dim the lights. Simultaneously pour the luminol and hydrogen peroxide solutions into the funnel. A blue glow can be observed for approximately two minutes after initial mixing.

http://www.glowspace.com/classroom.htm

- Luminol solution:
- 4 g sodium carbonate
- 0.2 g luminol
- 24.0 g sodium hydrogencarbonate
- 0.5 g ammonium carbonate
- 0.4 g copper(II) sulfate-5-water
- 1 dm^3 distilled water

Mix to dissolve.

- Hydrogen peroxide solution:

Dilute 50 cm^3 of 3% hydrogen peroxide to 1 dm^3. Final solution is approximately 0.15%.

Mix about 200 cm^3 of each of the two solutions in a conical flask.

http://www.chm.bris.ac.uk/webprojects2002/fleming/experimental.htm

- Luminol solution:
- 4 g Na_2CO_3
- 0.2 g luminol
- 24 g $NaHCO_3$
- 0.5 g $(NH_4)_2CO_3.H_2O$
- 0.4 g $CuSO_4.5H_2O$

All dissolved in 1 dm^3 H_2O

Mix to dissolve.

- Hydrogen peroxide solution:

50 cm^3 of 30% H_2O_2 diluted to 1 dm^3 in H_2O. Final solution is approximately 1.5%.

Add the hydrogen peroxide solution to the luminol solution. A very bright, fast reaction is observed.

Catalyst: $[Fe(CN)_6]^{3+}$

http://www.york.ac.uk/org/seg/salters/chemistry/ResourceSheets/luminol.PDF

- Dissolve 0.1 g of luminol in 20 cm^3 of sodium hydroxide solution (0.5 mol dm^{-3}) and make up to 100 cm^3 with water.
- Make 100 cm^3 of a 5% solution of potassium hexacyanoferrate(III).

Add small portions of each solution to a beaker and observe the light emitted. You will probably need to darken the room or build an enclosed darkened area. You will also need to measure the amount of light emitted with a light meter. ProBase note: This appears incomplete since the quantity of hydrogen peroxide used is not given.

http://www.chm.bris.ac.uk/webprojects2002/fleming/experimental.htm

Dissolve 4 g Na_2CO_3 in 500 cm^3 H_2O. Add 0.2 g luminol and dissolve. Add 25 g sodium hydrogencarbonate and 0.2 g ammonium carbonate monohydrate. Dilute to 1 dm^3 and use a 25 cm^3 portion for each reaction.

Dissolve 0.76 g $K_3[Fe(CN)_6]$ dissolved in 25 cm^3 of 5% H_2O_2 solution.

Mixing the two solutions gave a lasting glow of more than 50 seconds. Because the catalyst in this reaction is strongly coloured the light appears green.

Catalyst: Co^{2+}

Automated Flow-Injection Instrument for Chemiluminescence Detection Using a Low-Cost Photodiode Detector. A. Economou, D. Papargyris, and J. Stratis, Journal of Chemical Education 2004, 81, 496

Luminol, hydrogen peroxide, sodium hydroxide, and cobalt(II) sulfate-7-water are analytical grade. Distilled water is used to prepare all solutions. Stock solutions required:

- 0.01 mol dm^{-3} luminol
- 10 g dm^{-3} cobalt(II) sulfate-7-water
- 1 mol dm^{-3} sodium hydroxide
- 0.1 mol dm^{-3} hydrogen peroxide (about 0.34%)

Typical starting concentrations:

- luminol: 0.001 to 0.01 mol dm^{-3}
- hydrogen peroxide: 0.002 to 0.02 mol dm^{-3}
- sodium hydroxide: 0.0001 to 0.001 mol dm^{-3}

A calibration graph is constructed using Co(II) solutions in the concentration range 0.5–200 mg/dm^3. A Co(II) solution of unknown concentration is analysed from the intensity of emitted light using the calibration graph.

http://www.chm.bris.ac.uk/webprojects2002/fleming/experimental.htm

- Dissolve 11 g Na_2CO_3, 8 g $NaHCO_3$ and 0.2 g luminol in 1 dm^3 distilled water. Add 25 cm^3 of 3% H_2O_2 solution.
- Dissolve 0.1 g cobalt(II) nitrite in 1 dm^3 H_2O

Mix the two solutions. Less bright than the copper(II)-catalysed reaction, but lasts longer and is useful experimentally.

ProBase note: 'Cobalt(II) nitrite' is almost certainly a mistake in the original text and it should be cobalt(II) nitrate-6-water.

Thinking about the proposal for a detailed study

Here are some ideas you might consider when reflecting on your initial investigations and planning a more detailed study:

- Quantitative measurements of chemiluminescence will be required. How might this be done?
- What reaction conditions might be altered?
- How would you produce a calibration graph?
- Find out about constant flow techniques. How can these be used in the analyses (hint: think about the Y-tube suggestion).

You may well come up with other ideas. Discuss these in your group before starting to write your own proposal.

Student datasheet:
Data to support costed detailed investigation proposal

Variables to be studied in more depth
Summary of the planned experiments
Estimated cost of consumables for the planned experiments
Estimated time required and associated staff costs

Teacher's document

Overview
Students take the role of analytical scientists working in an environmental laboratory. An important part of the laboratory's work is analysis of water, in particular the determination of very low metal ions concentrations in water. Their manager has heard about the use of chemiluminescence as an analytical technique. She has asked the analytical team to find out more about chemiluminescence and its potential use in analysis. She wants the team to carry out some initial research, write a brief report on it and propose a costed research programme to investigate more fully the potential of luminol chemiluminescence in metal ions analysis.

Scientific skills and knowledge
Students:
- tackle scientific problems by applying their practical skills and their knowledge
- observe, measure and analyse data collected and to evaluate these.

Other professional skills
Students:
- work with others and manage relationships with people
- manage resources and budgets
- communicate.

Context
Students tackle issues associated with being in a team of analytical chemists investigating the potential of chemiluminescence as a technique to determine the concentration of metal ions in solution.

Developing students' skills
Guidance and help
Students need to recognise the importance of taking care and pride in their work. They need to be gently reminded of this while they are working. They may need three types of help.

- Help with technical details, including manipulative skills and correct handling of chemicals and equipment.
- Help with, and vigilance over, health and safety issues.
- Help with working relationships in their group.

Learning
The "assessment for learning" approach aims to help students identify their weaknesses and work to improve them. It is not intended to be used to 'give students marks'. See: http://www.presentingscience.com/aflchem/

When using questioning, do not intervene too soon with 'the answer'. Give students thinking time. Use questions as prompts for students to think about what they are doing. They need to be aware of the consequences to themselves and others of actions they take. Use relevant unambiguous questions. Allow plenty of time for students to respond. Involve all members of the group.

An effective series of questions might start with a closed question, followed by open questions. For example: *What was your result? How did you arrive at that result? Where else can you use this method? How can you improve the method?*

Organising and managing the class
Students should work in small teams, each consisting of an even number of students. Four or, preferably, six would be suitable.

Most of the work in this activity is practical. It does not require a great deal of equipment, but it does require access to a laboratory. How this is arranged depends on lesson time.

Notes on the tasks
Task 1: Changes that produce 'cold light' (luminescence)
It is suggested that all students in the team follow the instructions from *Inspirational chemistry- resources for modern curricula*: *7.4 Cold light*. They are straightforward and the experiment will start them thinking about 'cold light' and its different forms. Alternatively, students can be issued with **Student sheet***: Cold light*. To reduce the amount of materials and time needed, it is suggested that students work in pairs within their team.

Using **Student sheet***: Oxidation of luminol by sodium chlorate(I)* requires students to follow a method. The whole team should do this, working in their pairs.

The team then modifies the method to investigate the effect of changing some of the variables. Students note the colour/intensity of light produced, how long it persists and measure the temperature of the mixture. There are a number of variables. These might be allocated to different pairs, with the team sharing its combined results.

Each pair might be assigned one of these variables:
- the concentration of sodium chlorate(I) solution
- the concentration of luminol in the alkaline luminol solution
- the concentration of sodium hydroxide in the alkaline luminol solution
- the temperature of the reaction mixture.

If possible, provide a light meter so that students can try to quantify their observations, though the reality is that this is hard to do. A darkened room is essential. The other problem is that chemiluminescence is very bright initially, but this usually fades quite rapidly. In **Datasheet***: Oxidation of luminol using hydrogen peroxide* a simple piece of apparatus is described for continuous mixing of fresh reactants. This prolongs the initial brightness of the chemiluminescence.

Task 2: The catalytic oxidation of luminol
Each team carries out a series of exploratory investigations into the possible use of chemiluminescence as an analytical technique to determine the concentration of metal ions in solution. It is suggested that each team continues to work in pairs, each pair being assigned one of these metal ions to investigate:
- hexaaquacopper(II), $[Cu(H_2O)_6]^{2+}$
- hexaaquacobalt(II), $[Co(H_2O)_6]^{2+}$
- hexacyanoferrate(III), $[Fe(CN)_6]^{3-}$

Students are likely to need help in coming up with a realistic and realisable plan.

Task 3: Proposal for a detailed study
This task draws the activity together. The proposal requires students to propose a series of experiments, estimate the cost (manage resources and budgets) and write the proposal (communication).

The series of experiments should recognise the need to make quantitative measurements. While the students will have no direct experience, they should be able to suggest that the brightness of the chemiluminescence might be measured using light detectors (e.g. a light meter). They may do some research to find out what types of meter are available. It does not matter if they cannot identify a suitable one. It is sufficient if they recognise that one is needed and that they may need to try one or two models to see which is best suited to the purpose.

They should recognise the need to produce a calibration graph (they might be guided to this idea by thinking about colorimetry or spectrophotometry).

They might also be encouraged to find out about constant flow techniques and how these are used in analysis (linking this to the Y-tube experiment).

Session plan for teachers
The problem students tackle is to investigate the potential of chemiluminescence as an analytical technique. The work involves many aspects and can only be completed if students work in teams.

A suggested approach is:
- Introduction to the activity and checking prior knowledge (about 30 minutes)
- Carry out task 1
  - Cold light: 60 minutes
  - Oxidation of luminol by sodium chlorate(I): 90 minutes
  - Finding out about fluorescence and chemiluminescence: 30 minutes
- Carry out task 2
  - Reading sheet and planning experiments: 40 minutes
  - Carrying out practical work: 200 minutes
- Carry out task 3 (about 150 minutes)

Technical notes

- **Preparation**

Working environment and conditions
Students need to work in a laboratory for about 260 minutes. Other work may be done outside the laboratory.

- **Equipment and Materials**

Materials and their CAS numbers

ethanol	64-17-5
sodium chlorate(I) solution	7681-52-9
Note: also known as sodium hypochlorite	
hydrogen peroxide	7722-84-1
luminol	521-31-3
sodium hydroxide	1310-73-2
sodium carbonate	497-19-8
sodium hydrogencarbonate	144-55-8
ammonium carbonate monohydrate	506-87-6
copper(II) sulfate-5-water	7758-99-8
potassium hexacyanoferrate(III)	13746-66-2
cobalt(II) sulfate-7-water	10124-43-3

Note: One 'literature' preparation says cobalt(II) nitrite is used (http://www.chm.bris.ac.uk/webprojects2002/fleming/experimental.htm)
It seems unlikely that it is used (cobalt(II) nitrite cannot be found in chemical suppliers' catalogues).
Cobalt(II) nitrate is more likely (CAS number 10141-05-6).

Equipment
Each student or pair of students will require:

Cold light
white light – lamp or torch
UV light
a few spinach leaves
knife
tile or plate
ethanol
beaker
boiling tube and bung
glass rod
clear boiled sweet in wrapping
(transparent hard sweet of crystallised sugar, still in its plastic wrapping)
plastic bag
pliers
white paper
washing machine powder
fluorescent pens
brown paper (parcel paper)
glow-in-the-dark sheet
tonic water

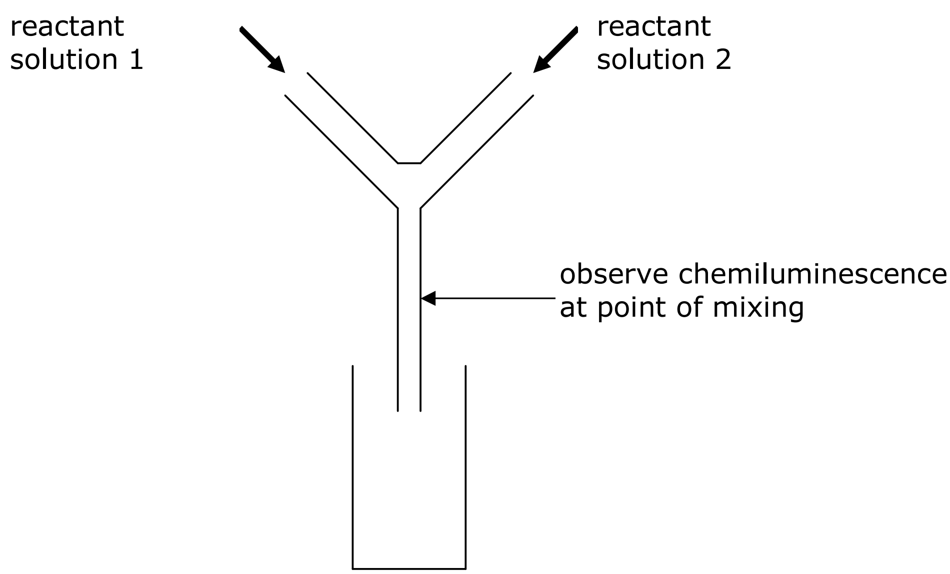
gypsum, calcite or fluorite (minerals)
eye protection

Chemiluminescence: Oxidation of luminol by sodium chlorate(I)
To make the stock solutions:
- 2 x 1 dm^3 conical flasks with stoppers
- 1 x 2 dm^3 beaker
- balance weighing to 0.1 g

To investigate the reactions:
- boiling tubes and test tube rack
- thermometer (0–100 °C)

The following solutions may be made in advanced for the students to use:
- Sodium chlorate(I) solution, about 0.08 mol dm^{-3}, prepared by adding 50 cm^3 of 13% sodium chlorate(I) solution to 950 cm^3 of distilled water in a flask, mixing well and stoppered.
- Alkaline luminol solution, about 0.002 mol dm^{-3}, prepared by putting 0.4 g of luminol into a flask containing 4.0 g of sodium hydroxide and dissolving in 1 dm^3 of distilled water. Swirl to dissolve the chemicals and then stopper the flask. The luminol does not always appear to dissolve completely, leaving a fine, greenish suspension.

Oxidation of luminol using hydrogen peroxide
Requirements per student or pair of students depend on how the work is divided between the team and the experiments that students plan.
Details are provided in the datasheet. Equipment and materials required will depend on the students' plan. However, boiling tubes, test tube rack and Y-tube are most likely to be used.



- **Light meters**

The possible use of light meters for measuring the intensity of chemiluminescence is mentioned in the student text. Light meters vary greatly.

An example of one that might be used in the VOLTCRAFT LX-1108. It has these specifications:

- range 0-400.000 lux
- resolution 0.01 lux
- spectral adjustments: sunlight, mercury lamps, sodium lamps
- price about 140 €

Some places to look for light meters:
http://www.reliabilitydirectstore.com/Light-Meter-ss/32.htm?gclid=CLiynfrBt5MCFRlPEAodH3RmCg
http://www.digital-meters.com/Light-Meter-p-1-c-256.html
http://www.maplin.co.uk/Module.aspx?C=SO&U=strat320&T=sitenew&ModuleNo=46557

Of course, they are sensitive to 'stray' light. Therefore any experimental set-up must exclude this light and ensure that only light from the chemiluminescence is received by the meter.
The reaction vessel needs to be confined within a dark space (e.g. a thick cardboard box) and a 'viewing' hole cut against which the meter can be pressed.

You can find out about light meters at http://en.wikipedia.org/wiki/Light_meter

Testing prior knowledge

1. What is the oxidation number of oxygen in:
    a. water Ans -2
    b. hydrogen peroxide Ans -1
    c. oxygen gas Ans 0

2. Acidified potassium manganate(VII) oxidises hydrogen peroxide. Which of the following statements are true?
    a. Oxygen gas is produced TRUE
    b. The oxidation number of oxygen in hydrogen peroxide increases TRUE
    c. The oxidation number of oxygen in hydrogen peroxide decreases FALSE
    d. The oxidation number of oxygen in hydrogen peroxide doesn't change FALSE

3. Hydrogen peroxide oxidises potassium iodide. Which of the following statements is true?
    a. Water is produced FALSE
    b. The oxidation number of oxygen increases FALSE
    c. The oxidation number of oxygen decreases TRUE
    d. The oxidation number of oxygen doesn't change FALSE

4. For a catalysed reaction, which of the following statements are false?
    a. A catalyst does not take part in the reaction FALSE
    b. A catalyst can be recovered unchanged chemically after the reaction TRUE
    c. A catalyst increases the rate of the reaction TRUE
    d. A catalyst decreases the released heat in an exothermic reaction FALSE

Note: Correct answers are given in red. These need to be removed before the test is used.

Testing prior knowledge

1. What is the oxidation number of oxygen in:
    a. water
    b. hydrogen peroxide
    c. oxygen gas

2. Acidified potassium manganate(VII) oxidises hydrogen peroxide. Which of the following statements are true?
    a. Oxygen gas is produced
    b. The oxidation number of oxygen in hydrogen peroxide increases
    c. The oxidation number of oxygen in hydrogen peroxide decreases
    d. The oxidation number of oxygen in hydrogen peroxide doesn't change

3. Hydrogen peroxide oxidises potassium iodide. Which of the following statements is true?
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    b. The oxidation number of oxygen increases
    c. The oxidation number of oxygen decreases
    d. The oxidation number of oxygen doesn't change

4. For a catalysed reaction, which of the following statements are false?
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