Rusting of steel wool using vinegar

Posted by Anonymous on Fri, 2016-03-18 15:34

We are doing the rusting of steel wool with vinegar experiment with our Year 8 students. There are various versions of this experiment on the net, this is one example: http://www.sciencekids.co.nz/experiments/steelwoolvinegar.html

Our students are given a range of liquids (water, salt water, vinegar, oil, and soft drink) to investigate which liquid produces the greatest temperature increase and the largest amount of rust. Our method is: soaking the steel wool in the liquid, removing the steel wool and squeezing and flicking off as much of the liquid as possible. The steel wool is then wrapped around the bulb of a thermometer. A paper towel is then wrapped around the steel wool ball and held in place with a rubber band. The temperature is recorded for 10 minutes.

The steel wool in vinegar produces a rise in temperature, sometimes the temperature goes above 50 °C. None of the other liquids show any temperature increase. After 10 minutes, students unwrap the steel wool and observe any changes. The steel wool in vinegar always looks rusty and the paper towel is stained. The salt water and soft drink sometimes produce brown staining on the paper towel, but no visible change to the actual steel wool. The other liquids don't produce any change.

I have run some additional experiments to find out what is really happening. I have used hydrochloric acid and sulfuric acid at various concentrations, I have also tried sodium hydroxide and bleach. None of these solutions produce a significant amount of rust and no visible change to the steel wool,.The acids produced some staining of the paper towel, the bases did nothing. The sulfuric acid produced a small rise in temperature from 25 to 28 °C. I have also tried 5% acetic acid (same concentration as the vinegar), this produced almost as much rust as the vinegar and a temperature rise to just over 40 °C.

The success of the experiment depends on how much liquid is removed from the steel wool after soaking. The more liquid removed, the higher the temperature and the greater the amount of "rust". Nothing happens if the steel wool is too wet.

I have the following questions about this experiment.

1. Safety: The steel wool smells really bad after it is removed from the vinegar. It smells a bit like a combination of foul eggs and fish. I thought maybe the steel wool contained some iron sulfides. The fishy smell may indicate amines. What are the gases (smell) produced, are they toxic?

2. Why is it only vinegar that produces such a large temperature increase and a large amount of "rust"?

3. Why doesn't the experiment work when the steel wool is too wet?

4. What are the actual products of the reaction with vinegar. I have a feeling they could be a combination of iron acetates and oxides. I suspect the hydrochloric acid produces chlorides and the sulfuric acid produces sulfates. Maybe these reactions are less exothermic than the acetates. Or maybe the vinegar acts as a catalyst?

I would be very grateful if you could answer some of these questions.

Voting:

Average: 5 (1 vote)

Year Level:
8
Laboratory Technicians:
Laboratory Technicians

Showing 1-1 of 1 Responses

Answer by Poonam hosany on question Rusting of steel wool using vinegar

Submitted by sat on 04 April 2016

The steel wool and vinegar rust experiment is a great example to illustrate the highly exothermic rusting process. The most appropriate way to perform this experiment is to place steel wool and a thermometer in a covered beaker to get an initial stable temperature. Then the thermometer is removed and the steel wool allowed to soak in vinegar for 1 minute. The steel wool is then removed from the vinegar and all excess liquid squeezed out. The steel wool is then wrapped around the thermometer and both are placed in the covered beaker. The temperature increase is then recorded until a maximum temperature is reached.

As you suggest, steel wool can contain sulphur as an impurity. Vinegar (4–5% acetic acid) has a characteristic pungent smell and often contains sulphides as preservatives. During the steel wool–vinegar rust experiment, a pungent and foul rotten-egg smell is observed, which is due to the generation of hydrogen sulfide (H_2S) gas. When the steel wool is allowed to soak in the vinegar, the rotten-egg smell sharpens and during the rusting process the smell is even more prominent due to the high temperature.

Hydrogen sulfide can be detected at very low levels; its threshold detection concentration (0.008 ppm[1]) is at least 500 times below the level at which it can cause adverse health effects.[1] Hydrogen sulfide is a toxic gas, however, at low concentrations, health significant effects would not be expected, although the smell may cause annoyance or anxiety. At concentrations of 2–4 ppm, people may experience eye irritation and in sensitive individuals such as asthmatics, respiratory irritation may occur.[1] Chronic exposure to low concentrations may lead to headache, fatigue and nausea. Hydrogen sulfide is broken down in the air and with low-level exposure, any that is absorbed is rapidly metabolised and does not accumulate in the body.[1]

Dry steel wool does not rust because of its microscopic oil coating. During the manufacture of steel wool, oil is put onto the cutting tools to minimise the fire hazard by reducing friction. When soaked in vinegar, the acetic acid removes the protective coating on the steel wool and the iron is able to rust. Acetic acid is a hydrophyllic (polar) solvent. Due to its moderate dielectric constant, it can dissolve non-polar compounds such as oil and is widely used as a degreaser. Mineral acids such as hydrochloric acid and sulfuric acid, though stronger than acetic acid, are not able to remove the protective coating at low concentrations and therefore the rusting process is slower, less exothermic and the yield is smaller. If the steel wool is soaked in 2 M sulfuric acid or hydrochloric acid for a longer period of time, then the mineral acids will be able to break down the protective oil coating and react with iron to give iron (II) sulphates or chlorides and liberate hydrogen gas.

Once the protective layer is removed, excess vinegar is squeezed out so as to expose the iron to the atmospheric oxygen. When the steel wool is wet, the liquid seeps into the iron’s tiny gaps and serves as an electrolyte to allow the electrons from oxygen to gravitate towards the iron. If the steel wool is too wet, the reaction will be less exothermic and yield less rust. This is because the acetic acid from the vinegar will react with the iron from the steel wool to form iron acetate and hydrogen gas.

The products obtained from the steel wool–vinegar experiment is mainly rust—brown, a reddish-brown solid and unreacted iron. As long as the steel wool is not left immersed in the vinegar, iron acetate is not formed and this can be easily confirmed by a simple reaction with ammonium hydroxide solution. Some distilled water is added to the solid product, and 5 mL of the suspension formed is transferred to a test tube and 5 mL of 0.1M ammonium hydroxide is added. The absence of a green precipitate (iron (II) hydroxide) confirms that iron acetate is not present.

Science ASSIST recommends the following when doing this experiment.

- Suitable PPE should be worn when handling steel wool, such as: protective clothing, nitrile gloves and safety glasses.
- Ensure that there is good ventilation in the laboratory when conducting the experiment.

- Keep the steel wool in its original packaging away from electrical outlets or other sources of electricity or flame. (Note: Incomplete combustion of steel wool will produce carbon monoxide, a toxic gas.)
- Store the steel wool in a cool, well-ventilated area away from incompatible chemicals such as acids and strong oxidizing agents.
- Keep the exposure to the steel wool to a minimum and minimise the quantities kept in work areas.

Additional Information

The **rusting** of iron is a redox chemical process that takes place when the metal is exposed to water, oxygen and an electrolyte. The corrosion process is complex and proceeds through the formation of the hydrated oxides, $Fe(OH)_3$ or $FeO(OH)^2$ .The final product of the process, the reddish brown solid we know as 'rust', is composed of the hydrated iron oxide, $Fe_2O_3.nH_2O$.

The 2 distinct chemical reactions in the corrosion process are:

1. Anodic oxidation and dissolution of iron

$2Fe_{(s)}$? $2Fe^{2+}_{(aq)} + 4e^-$

2. Cathodic reduction of oxygen

$O_{2\ (g)} + 2H_2O_{(l)} + 4e^-$? $4OH^-_{\ (aq)}$

The overall equation is:

$2Fe_{(s)} + O_2 + 2H_2O$? $2Fe(OH)_2$

The iron (II) hydroxide is further oxidised to give the final red product, rust, $Fe_2O_3.nH_2O$.

Vinegar contains significant amounts of polyphenols (antioxidant plant chemicals) and minute traces of minerals such as potassium, sodium, calcium and vitamins as well as sulfites in the form of preservatives. The acetic acid in vinegar is formed as a by-product of the fermentation process involving yeasts, harmless microorganisms which convert natural sugars to alcohol under specific conditions, and bacteria of the genus 'Acetobacter' which convert the alcohol to acid.

Steel wool is made up of low-grade carbon steel wire, commonly known as mild steel. Mild steel is a low-cost material with a composition of 0.05–0.25% carbon, 98–99% of iron, 0.6–0.9% manganese and up to 0.4% silicon. Residual elements such as nickel, chromium, aluminium, molybdenum and copper may be present in addition to impurities such as phosphorus and sulfur.

Steel wool is a biodegradable material and is commercially available in 8 different grades or thicknesses from coarse to extra fine. The finer the metal, the less harsh it is. The 8 different grades are listed in the table below.

Grade	Number	Common Uses

Coarse	3	Paint and varnish removal, removing paint spots from resilient floors, cleaning glass blocks
Medium coarse	2	Removing scratches from brass, removing paint spots, removing rust and dirt from garden tools.
Medium	1	Cleans glazed tiles, removing stains from wood floors, cleans cast and wrought iron.
Medium fine	0	Brass finishing, cleaning tile, removing paints and varnishes and stubborn finishes
Fine	00	With linseed oil sanitizes high-gloss finishes
Extra fine	000	Removes paint spots or stains from wooden floors, cleans polished metal such as aluminium, smoothes finishes between coats, cleans vinyl and tiled floors
Super fine	0000	Final rubbing of finish, stain removal, antique restoration, polishes bright metals and removes dirt from glass

The Dielectric Constant (?) or relative permittivity, is a dimensionless constant that indicates how easily a material can be polarized by imposition of an electric field on an insulating material. As a measure of solvent polarity, a higher ? indicates that the solvent has a higher polarity, and therefore a greater ability to stabilize charges.[3]

Water, being a very polar solvent, has a high dielectric constant of 80 at 20 °C. For non-polar solvents such as hexane and cyclohexane, ? is close to 2, while for acetic acid, ? is 6.2.[4]

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