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Norbert Rillieux and the sugar industry

Teachers' notes

Objectives

- To be able to use correctly the words associated with solutions and dissolving.
- To understand the difference between a solution and a saturated solution.
- To appreciate the difficulties faced by black scientists in the 19th century.

Outline

This materially is divided into two distinct pieces of work

- **Sparkling white crystals of sugar** The student worksheet includes information about Norbert Rillieux and explains how difficult it was for him, as an African-American, to be a scientist in the 1800s.
- **Extracting sugar from sugar beet** Practical and paper based exercises on the laboratory and industrial processes.

Teaching topics

These activities are suitable for 11–14 year old students and could be included when teaching about solutions and the separation of mixtures or using neutralisation to remove impurities, using indicators to monitor the pH. It is a real application of neutralisation.

Extracting sugar from sugar beet could also be used with 14–16 year old students when teaching about rates of reaction, or acids and alkali. The extraction rate is dependent on surface area of sugar beet and this could be related to particle theory.

This activity can be used to develop practical skills such as extraction, purification, evaporation. It also presents the opportunity to show how social backgrounds can be responsible for the acceptance or rejection of a scientific idea and could be linked to citizenship.

Look at the student worksheets before reading these detailed teachers' notes.

Background information

Norbert Rillieux invents the vacuum evaporator

Rillieux's invention revolutionised the processing of sugar. In 1846 he received a patent for a multiple-effect vacuum evaporator that turned sugar cane juice into a fine grade of white sugar crystals. Rillieux's process was more efficient and economical than any other method. His basic process is still used throughout the sugar industry today.

Most of the well known scientists, engineers and inventors of the 18th, 19th and early 20th centuries are white and male, and many of them come from Western Europe. Have you ever wondered why there are not many well-known black scientists and engineers? Perhaps the answer lies in the social status of black people, especially in the

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United States of America during that time. Before the American Civil War, most black people were slaves and slaves were not considered to be people capable of being creative and having the ability to invent worthwhile things. However, all the time black craftsmen were inventing tools to help them in their daily jobs. Other people, outside of the slave communities, would not have heard about their inventions, and if they had, the inventions would not have been taken seriously. Worthwhile ideas perfected by blacks were often lost forever because of the attitude of the Federal government in the USA at the time. In 1858, Jeremiah S. Black, Attorney General of the United States, had ruled that since a patent was a contract between the government and the inventor, and since a slave was not considered a United States citizen, he could neither make a contract with the government nor assign his invention to his master. Thus it has been impossible to prove the contributions of many unnamed slaves whose creative skill has added to the industrial growth of the USA.

The national ban on patents for slaves did not apply to patents made by ‘Free Persons of Colour’, (or ‘free Blacks’) and so James Forten (1776–1842) perfected a new device for handling sails and Norbert Rillieux had no trouble in getting a patent. Rillieux’s mother was a slave but his father was the slave owner and unlike most ‘mixed race’, he was sent to L’École Centrale in Paris to be educated. Before the end of the Civil War many of the ‘free Blacks’ worked to save those others in bondage. They did so by developing their literary and speaking ability rather than becoming scientists and so what they did may have limited the progress of science.

Following the Civil War, growing American industries were extensively using ideas from both black and white people and by 1913, it is estimated that black people had patented about one thousand inventions. The race of the inventor was no longer recorded on the document after Henry Blair, the first black American to receive a patent in 1834, received his second patent in 1836. Even so, it was common for inventors to take out patents in the name of a lawyer because they felt their racial identity would lower the value of the patented invention.

The following things were all invented and patented by black Americans[2]

Inventor	**Invention**	**Date**	**U.S. Patent No.**
E. McCoy	Lubricator for steam engines	2/7/1872	129,843
G.T. Sampson	Clothes drier	7/6/1892	476,416
R.A. Butler	Train alarm	15/6/1897	584,540
J.A. Burr	Lawn mower	9/5/1899	594,059
G.F. Grant	Golf tee	12/12/1899	638,920

And there are many other examples.

Box 1 shows the original Rillieux evaporator.

Box 1

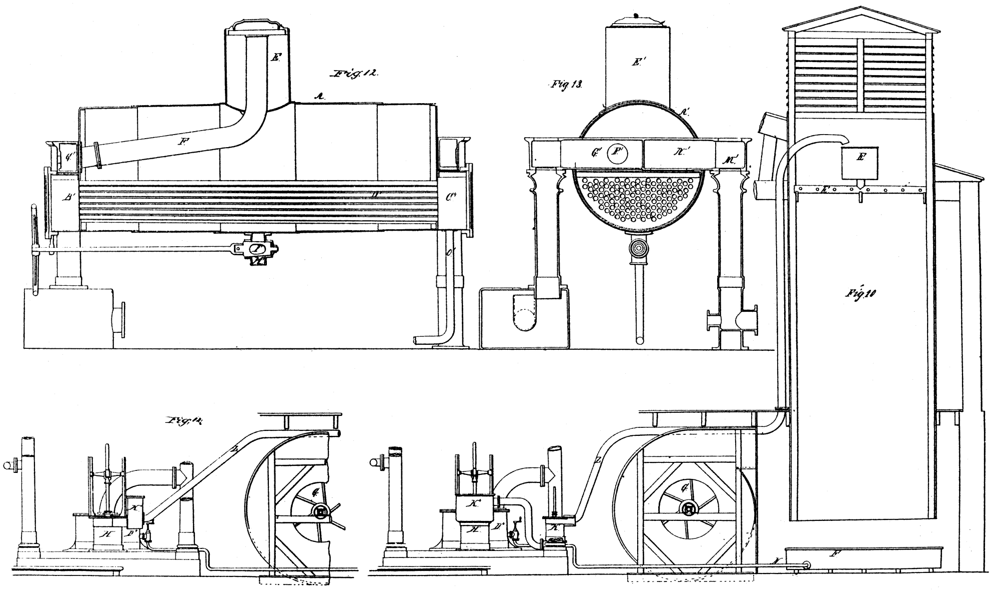

Figure 1 The Rillieux Evaporator (U.S. Patent number 4879, December 10th 1846)

A series of vacuum pans, or partial vacuum pans, have been joined together. The sugar juice in the first pan is heated and water is evaporated off. The water vapour is passed to the second where it is used to heat up the next lot of sugar juice. More water is evaporated off and once again the vapour is passed to the third pan where it is used to heat up more sugar juice. The third and last pan is connected to a condenser, and so the water vapour cools down and condenses back to a liquid. The technique works because the second pan is at a lower pressure than the first, and the third pan is at a lower pressure than the second. This means that the vapour will be 'pulled' towards the next pan. In theory there is no limit to the number of pans in the system, but in practice the number is limited because the temperature of each pan is lower.

Advantages of the system

- **Safer** – previously slaves transferred the boiling juice from the steaming open kettle to the next by means of a long ladle.
- **Lower boiling temperatures** resulted in greatly reduced losses of sugar in the process.
- **Reduced costs** of labour and fuel.

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The modern process

See photocopiable sheet **The modern process of sugar extraction**.

British Sugar York Process Flows

Clean beet
Sugar beet is passed to the factory via an underground passage and "overhead trough" which cleans the beet to a certain extent (removing loose soil and trash). The beet is dried over a vibrating screen before it enters the factory.

Cossettes
After slicing, the beet takes on the appearance of thin french fries. These are called cossettes (derived from a French word) which are the optimum shape to allow maximum extraction of sugar whilst retaining mechanical stability, which is important for later pressing. At York, cossettes pass over a weigher, which gives a figure upon which to base most process flow numbers. At York, a typical flow of cossettes would be 390 tonnes per hour. This figure will be used for all following flow rates.

Diffusion
This is a process where cossettes and water pass one another in a counter-current flow. The flow of water is ratioed to the flow of cossettes using a figure called Draft. A draft of 117, which is typical for York, means that for every 100 tonnes of cassettes entering the diffuser, 117 tonnes of water will be added at the other end.

The water entering the diffuser is a mixture of borehole water (*ie* fresh water) and water returned from the pulp presses. This is called Diffusion Supply Water or DSW. DSW is typically in the pH range 5.0 to 5.7. This is controlled through the addition of a dilute solution of sulfuric acid to lower the pH. Diffusion tends to be carried out under acidic conditions to assist extraction of sugar and maintain pressability of the pulp leaving the diffuser.

Raw juice
This is the juice containing all species extracted from the cassettes. Flow of raw juice is in the region of 121% of beet sliced, which equates to 472 tonnes per hour. The pH of raw juice is in the region of 7.0 to 9.0. This is not really controlled as such, but some process streams are returned to raw juice, which can be used to alter the pH if it becomes necessary. No specific chemical is used to alter the pH.

Carbonatation
This is the primary purification stage in the process. Raw juice is mixed with a slurry of slaked lime and carbon dioxide gas is bubbled through this mixture to eliminate most of the impurities present. The slaked lime slurry is called Milk Of Lime or MOL and is made by mixing burnt lime (from the limekiln) with sweet water (*ie* water containing small amounts of sugar, to improve the solubility of the calcium). The flow of MOL is ratioed to the raw juice flow at approximately 1:10 MOL to raw juice, to a rate of around 45 cubic metres per hour of MOL.

Carbonatation is split into two stages, 1st and 2nd Carb. In 1st Carb, MOL is mixed with raw juice in a tank, which will raise the pH to around 13. This mixture is then "gassed down" with carbon dioxide gas (from the limekiln) to a target pH of 11.5. The target pH is controlled by the rate of gas addition rather than increasing or decreasing MOL flow. Residence time in the 1st Carb stage is around 10 minutes, such that a unit of juice entering will pass between mixing and reaction tanks for 10 minutes before passing forward. The resultant mixture of lime and juice is then allowed to settle in a clarifier before the supernatant liquor goes to 2nd Carb.

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In 2nd Carb, further addition of carbon dioxide gas takes place to further lower the pH and precipitate out any remaining dissolved calcium salts. Target pH in 2nd carb is 9.2, ranging from 8.5 to 9.7 dependent upon gas flow.

Thin juice
Juice leaving the 2nd Carb stage is filtered and sulfur dioxide (in a gaseous form from a sulfur stove) is added to prevent colour formation. The addition of sulfur dioxide has a tendency to depress pH, so some addition of either sodium carbonate or magnesium oxide is made to keep the pH in the range 8.0 to 9.2. The resultant juice is called thin juice, with a flow rate of around 117% beet sliced or 456 tonnes per hour.

Thick juice
Thin juice passes through a series of evaporators, which remove the majority of the water, to concentrate the juice to a level where it can be turned into crystal sugar. If the flow of thick juice leaving the evaporators is approximately 30% beet sliced (117 tonnes per hour) we see that 339 tonnes of water is removed from thin juice. No buffering of thick juice is done through the evaporators, so pH control is only done on thin juice.

The overall flow of 117 tonnes per hour of thick juice is then split between some going forward to make sugar crystal and some sent to tanks for storage and processing during the summer. This split is biased towards crystal production, with around 45% of the overall flow going to store. Before being sent to store, the juice is buffered to pH 9.2 by adding sodium carbonate solution and cooled to around 20 °C.

Juice to pans
The flow of thick juice to the sugar end of the factory is mixed with sonic sugars returning from 2nd and 3rd boiling stages, to give Juice to Pans or JTP. It is important to maintain a pH above 9 in the sugar end of the factory, so sodium carbonate can also be added direct to JTP if necessary. JTP flow is dependent upon the flow of juice to store, but is typically in the region of 65 tonnes per hour. The juice is then charged to a white pan, boiled under vacuum and seeded to produce a mixture of sugar crystals and a mother liquor. This mixture is called massecuite.

White sugar
The white massecuite is then separated into crystal and liquor in a batch centrifuge.

The liquor is reboiled to increase the overall sugar extraction, whilst the crystal is dried and then cooled before being stored in silos. The sugar produced passes over another weigher before entering the silos, at a rate of around 37 tonnes per hour, or around 10% of beet sliced.

Molasses
After the third boiling stage in the sugar end, the massecuite produced is separated into crystal and liquor in a continuous centrifuge. The crystal separated is mixed back in with thick juice and the liquor produced is molasses. Aside from white sugar and any losses in the process, molasses constitutes the only other route for sugar leaving the factory. Molasses is produced at a rate of around 11 tonnes per hour, or about 3% of beet sliced.

Sources of information

Information, Facts about British Sugar 1999/2000, Peterborough: British Sugar, 1999.

The British Sugar website **http://www.britishsugar.co.uk** (accessed September 2005).

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Sparkling white crystals of sugar

Teaching tips

This could be used as a follow up to a lesson on solutions, or a general revision lesson.

After a general discussion about Norbert Rillieux and life for coloured people in America in the 1800s, present the class with the problem Norbert Rillieux was faced with *ie* how to get white crystals of sugar.

Students could then carry out experiments A and B with the help of a partner, to see if they can obtain white crystals of sugar. To save time, half the class could carry out experiment A while the rest does experiment B, and then share the results.

Finally using the background information provided, tell the class how Rillieux solved the problem and the fact that British Sugar still base their manufacturing process on the principles thought up by Rillieux.

Rillieux's invention allowed the evaporation to take place at a lower temperature. You can obtain white crystals by putting the residue through a centrifuge and adding a small amount of water. Impurities that make the sugar go brown during the extraction (from sugarbeet or cane) process are generally the invert (*ie* glucose, fructose, and other saccharides) produced by the hydrolysis of the sucrose molecule, and the amino-nitrogen from the beet. These compounds can react together to form highly coloured species.

The experiments should be written up, using the words included on the student worksheet. You may wish to allow time to discuss the meaning of the words before they write up the experiments.

Resources

- Sugar
- Water
- Bunsen burner
- Tripod
- Gauze
- Pipe clay triangle
- Heat proof mat
- Beaker
- Evaporating basin
- Spatula
- Glass rod
- Student worksheets:
  – Sparkling white crystals of sugar (1)
  – Sparkling white crystals of sugar (2)

Timing

1 hour + homework

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Adapting resources

Sparkling white sugar crystals has been included as an example of how adjusting the required level of linguistic skills allows access to a wider range of students.

- **Sparkling white sugar crystals 1** has been written for more able students, with a high reading age.
- **Sparkling white sugar crystals 2** has been written for less able students, with a lower reading age.

It is hoped that the format of the student worksheet given here will be adopted and that teachers will use it to make up their own worksheets tailored to meet the needs of their own students and the topic being studied.

Opportunities for using ICT

Using the Internet to find out more about African-American scientists.

Answers

1. If Norbert Rillieux had been a white man his ideas and inventions would have been readily accepted. He would probably have been educated at home and not been sent to Paris. He would have been able to visit other scientists and sugar plantation owners freely; and he would probably have carried out more research and published more scientific papers. He might even be famous for a number of inventions now.

Dissolve – a physical change where particles of solute mix separately and intimately with particles of solvent.

Soluble – a substance that will dissolve in a solvent.

Insoluble – a substance that will not dissolve in a solvent.

Solvent – a liquid used to dissolve things.

Solute – a substance which dissolves in a solvent to make a solution.

Solution – formed when solids, liquids or gases dissolve in a solvent.

Saturated – a solution that contains as much of the dissolved substance as possible at a particular temperature.

Evaporate – when a liquid turns into a gas (at its surface).

Condense – when a gas turns into a liquid.

Crystal – a regular arrangement of atoms, ions, molecules or polymers.

2. In experiment A, crystals will not form and a brown sticky substance will be left behind. One of the problems is that during the heating the sugar crystals start to break down.

In experiment B, crystals should form, but it will take a long time for them to form, as the solution cools down slowly. In practice the seeding technique is used to induce crystallisation of the thick syrup.

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Extracting sugar from sugar beet

Teaching tips

Introduction to the lesson The lesson could start with the teacher spending 5 minutes talking about how we live in a multi-racial society where everyone has opportunity and then explain how difficult it was to be a black scientist in America in the 19th century. Introduce Norbert Rillieux and present the class with the problem he solved.

Problem In the sugar extraction process, when the final evaporation is carried out, the sugar molecules start to decompose, leaving a brown mess! This is the problem that the sugar industry was faced with, when they were extracting sugar. A 'seeding method', was used to induce crystals but the overall process was very slow.

Experiment Extracting sugar from sugar beet. Full experimental details are given in the teachers' notes. However, the procedure is lengthy and will take about three double lessons to complete the practical work. Therefore, you may wish to only carry out one part of the experiment or to use the paper exercise **Making sugar in the school laboratory**, which will help the class focus on some aspects of experimental method. This experiment is based upon material contained in the Sugar Challenge[3].

Follow up work or homework Extracting Sugar on an Industrial Scale Students should have no difficulty carrying out this work on their own, if they have completed the other activities. The industrial process follows the same procedure as on the laboratory scale. This is a good opportunity to point out that the science learnt in schools is actually used in the real world.

An alternative start to the lesson would be to follow on from the **Sparkling white sugar crystals** sheet. By then the class will have discovered the problem the sugar industry was faced with. The class can then be presented with Rillieux's solution to the problem by showing the diagram from the original patent together with an explanation. Then explain that we are going to see if vacuum evaporation really works.

Resources

- Sugar beet (or parsnips, carrots, beetroot)
- Chopping board and knife for slicing the sugar beet (or food processor)
- 1 dm^3 measuring cylinder
- Balance
- Bunsen burner, tripod, gauze, heat proof mat
- Large beaker and conical flask (1–2 dm^3)
- Porcelain tile
- *Milk of lime *ie* a suspension of freshly slaked lime
- Sampling pipette
- Carbon dioxide supply connected to a perforated rubber policeman (see Figure 2)
- Thymolphthalein and phenolphthalein or a pH meter or pH data logging equipment
- Apparatus for vacuum filtration (see Figure 3)
- Safety screen
- Safety glasses

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- Glass stirring rod
- 0–110 °C thermometer
- Apparatus for vacuum evaporation (see Figure 4)
- Jam jars (for storing the juice in) and sticky labels
- Refrigerator
- Student worksheets
  – Extracting sugar on an industrial scale
  – How to extract sugar in the school laboratory

Practical tips

***To slake quicklime** – heat a sample of quicklime (CaO) in a crucible for 15 minutes over a hot Bunsen flame. Test the sample by placing it in a beaker and adding a little water. If the water gets hot the lime is adequately slaked. To make the suspension continue to add water until the mixture has a consistency of emulsion paint. Use a safety screen while carrying this out.

Experimental instructions

1. Preparation of the beet

- Wash the sugar beet.
- Remove the stem of the beet.
- Weigh it and record its mass.
- Chop it up into long thin 'french fry' like pieces.- this will increase the surface area.
- Put the sugar beet pieces into a beaker of boiling water and gently simmer for about half an hour, until it is soft. (Roughly 1.2 cm^3 water / g beet) – to extract the sugar.
- Separate the beet from the sugar by decanting. The impure solution can be stored for up to a week in a refrigerator.

2. Purification of the liquid extract

- Heat the liquid extract to 80 °C.
- Add about 30 cm^3 of a suspension of freshly slaked lime ($Ca(OH)_2$) – to react with the acidic impurities. This should be made up fresh before the lesson.
- Carefully bubble CO_2 through the solution as shown in Figure 2.
- Regularly take samples with a pipette and test the pH, by dropping the sample on thymolphthalein paper or using a pH meter.
- Stop adding CO_2 when the pH reaches 11.2. The indicator will be pale blue.
- At pH 11.2, filter the extract under vacuum (see Figure 3). You may need to pre-filter through a piece of linen. Use coarse filter paper.
- Bubble CO_2 through the filtrate.
- Regularly take samples with a pipette and test the pH, by dropping the sample on phenolphthalein drops on a porcelain tile or using a pH meter.
- Stop adding CO_2 when the solution reaches pH 9 – the indicator will be light pink.

- Filter under vacuum, using a fine filter paper. The straw coloured filtrate is called 'Thin juice' and maybe stored in a refrigerator for up to a week.

3. Concentration of the juice by vacuum evaporation

- Set up the apparatus as in the diagram in Figure 4. As this takes a long time, pool the juice from several groups. It takes about 3 hours for 1 dm^3 to evaporate sufficiently at 40 °C under high vacuum. So it should be left to run over the subsequent lessons or lunchtime. Use a safety screen.
- Add the thin juice and continue evaporation until the juice has a consistency of thick porridge. 'Thick juice'.
- Turn off the vacuum.

4. Crystallisation

- Remove the thick juice and add a little icing sugar, stirring slowly.
- Crystals will become visible in the juice, which can then be filtered off. The crystals will be a bright brown colour.

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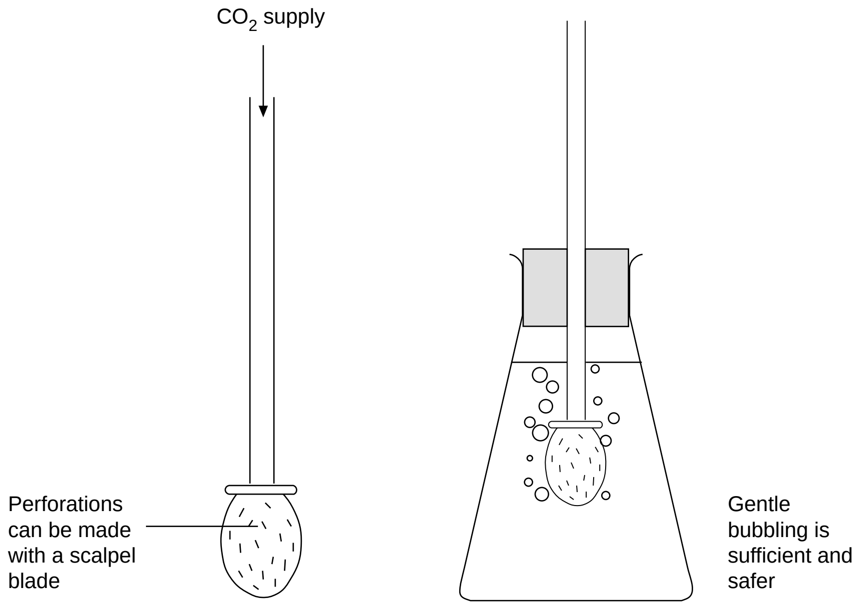

Figure 2 Perforated rubber policeman for CO_2 bubbling

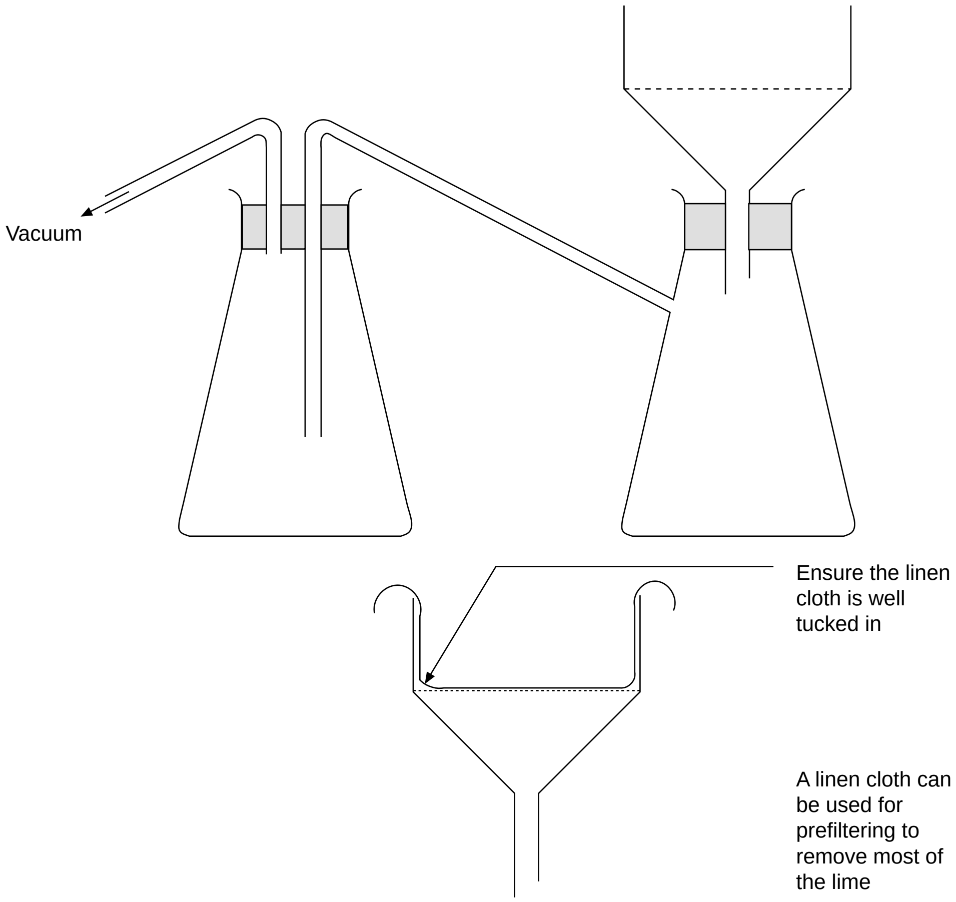

Figure 3 Apparatus for vacuum filtration

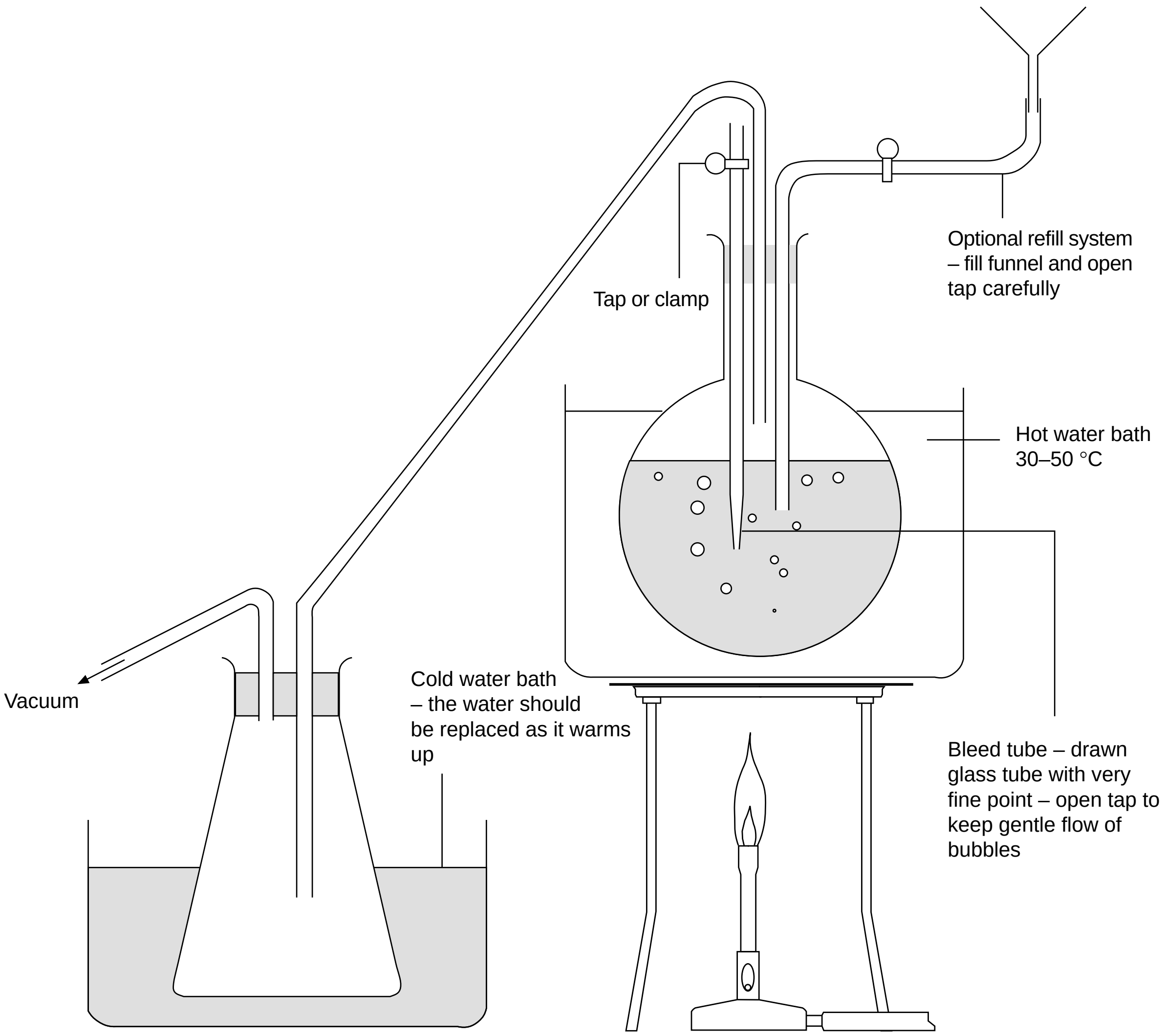

Figure 4 Apparatus for vacuum evaporation

Timing
The full extraction experiment will take between 6 and 8 hours.

The paper exercises **Extracting sugar on an industrial scale** and **Making sugar in the school laboratory** will take about 1 hour.

Adapting resources

Opportunities for ICT
Data logging An easy way to monitor the pH of the solution would be by a using pH probe connected to a computer. The stored data could be used at a later date to look at the rate at which the CO_2 removed the excess slaked lime.

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Answers

Making sugar in the school laboratory (a paper exercise)

1. The sugar beet is chopped up to increase the surface area during the extraction process.
2. The sugar particles dissolve in the water.
3. Lime is added to remove the acidic impurities.
4. The pH of lime is about 14.
5. Carbon dioxide is a weak acid and it is neutralised by the lime. As the concentration of lime decrease the pH also decreases.
6. Using a pH meter or a suitable indicator.
7. A vacuum lowers the boiling point of a liquid. This will allow the water to evaporate off at lower temperature so that the newly formed sugar crystals will not decompose, and not leave a brown mess in the reaction vessel.
8. Accept a description of, or a labelled diagram, showing how to filter by gravity or under vacuum.

Extracting sugar on an industrial scale

1. Sugar beet – a root crop that stores sugar in its root. The root swells up as it grows beneath the ground. It looks like a large parsnip.

   Continuous – the sugar beet extract flows directly from one place without stopping, until it reaches the end of the process.

   Crystallisation – is the process by which crystals are formed from a saturated solution.

   Batches – The reaction takes place in a big container. At the end of the reaction the product is emptied out and replaced with a new lot of reactant.

   Milk of lime – a suspension of calcium hydroxide.

   Power station – a place for generating electricity.

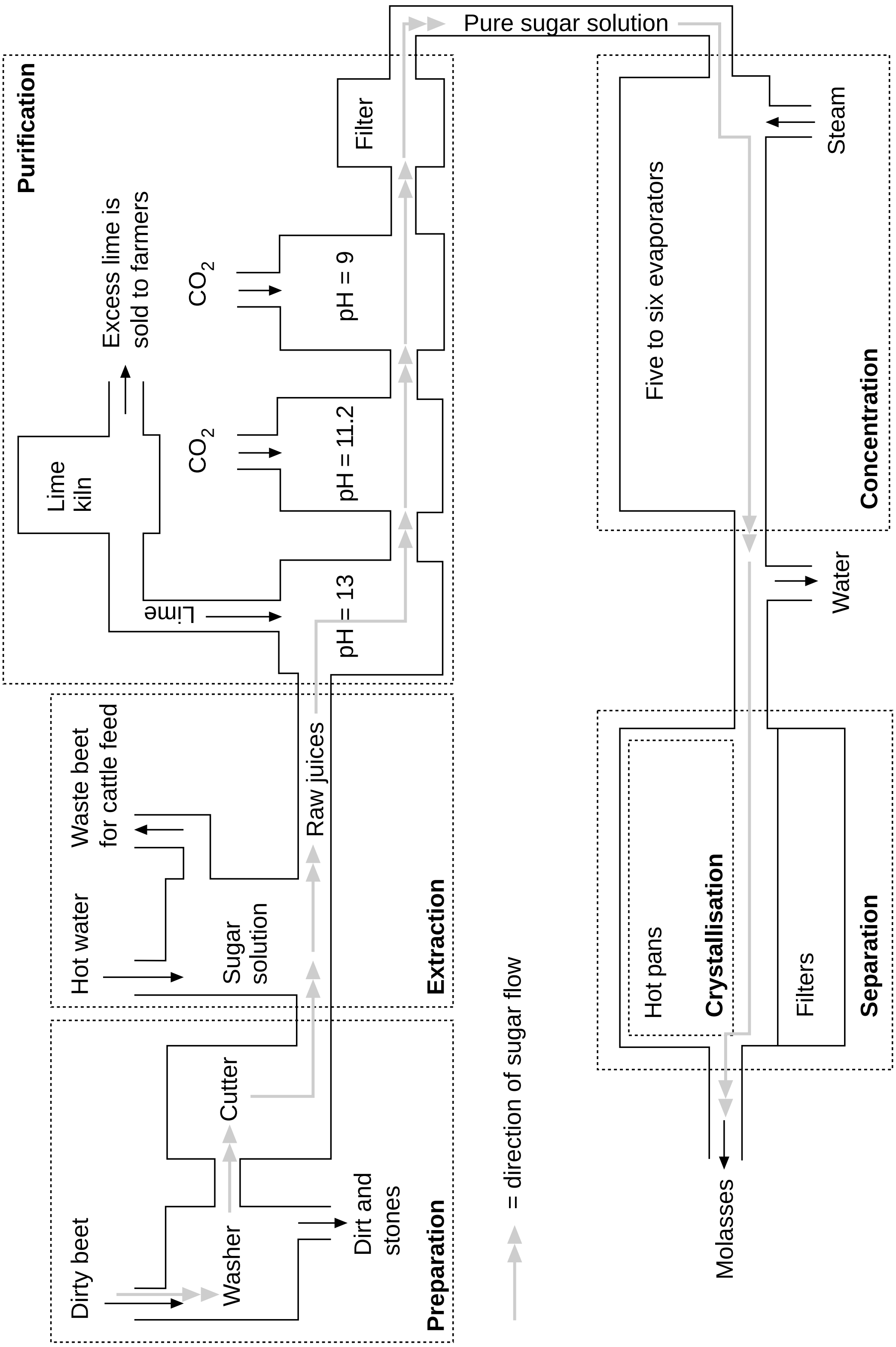
   Evaporators – the place where water is evaporated to leave a concentrated solution.

   National grid – the network that supplies electricity to individual houses and other buildings.

   By-products – extra products that are made during a reaction.

   Neutralise – this happens when acids and alkalis react together.

2. See diagram overleaf.


Preparation
Dirty beet
Washer
Cutter
Dirt and stones
Extraction
Hot water
Sugar solution
Waste beet for cattle feed
Raw juices
Purification
Lime kiln
Excess lime is sold to farmers
Lime
CO_2
CO_2
pH = 13
pH = 11.2
pH = 9
Filter
Pure sugar solution
Concentration
Five to six evaporators
Steam
Water
Crystallisation
Hot pans
Separation
Filters
Molasses
= direction of sugar flow

Sparkling white sugar crystals (1)

Norbert Rillieux solved the problem of obtaining white sugar crystals with his invention of the multiple vacuum evaporator in 1846. The new method was cheaper to run, safer to use and gave a better purity. Sugar factories today still use his process. Rillieux's scientific understanding was at least seventy years ahead of his time.

Norbert Rillieux
(Picture reproduced by courtesy of the Schomburg Center, New York Public Library)

Norbert Rillieux (1806–1894) Sugar Chemist and Inventor

Norbert was born in New Orleans, Louisiana. His father was an engineer and his mother a slave on his father's plantation. Norbert was not a slave but a 'free man of colour'.

He was sent to L'École Central in Paris to be educated, where at 24 he became a lecturer in applied mechanics. He published several papers on steam engines, before returning to Louisiana in 1834 and to work the sugar plantations. In 1846 he patented his vacuum evaporator.

Although recognised for his work he was socially unacceptable because of the colour of his skin. He was provided with a special house to live with servants, but he could not be entertained at the Plantation owner's house or in the house of any white man. There were also restrictions on his personal freedom, as there were on other 'free people of colour'. As social conditions got worse and the sugar industry was in decline he returned to Paris (around 1854), where he got interested in Egypt and hieroglyphics. He did not publish any more material on his sugar system until 1881 when he was nearly 75.

Norbert died in France in 1894. It has been said that Rillieux's invention of the sugar process was the greatest in the history of American chemical engineering.

Question 1. In what ways do you think that Norbert Rillieux's life would have been different if he had been a white man?

Question 2	Dissolve	Solute	Condense
What do the following words mean?	Soluble	Solution	Crystal
	Insoluble	Saturated	
	Solvent	Evaporate	

Experiment A
Dissolve some sugar in water. Evaporate off most of the water. Leave in a warm place. Do crystals form?

Experiment B
Make up a saturated sugar solution. Warm up the solution so that all the sugar dissolves. Add a sugar crystal and leave to cool.

What's the problem with this method?

Sparkling white sugar crystals (2)

Norbert Rillieux solved the problem of obtaining white sugar crystals in 1846. His method was cheaper to run, safer to use and gave a better purity. Sugar factories today still use his process. Rillieux's scientific understanding was years ahead of his time.

Norbert Rillieux
(Picture reproduced by courtesy of the Schomburg Center, New York Public Library)

Norbert Rillieux (1806–1894) Sugar Chemist and Inventor

Norbert was born in New Orleans, Louisiana. His father was an engineer and his mother a slave. Norbert was not a slave but a 'free man of colour'.

He was sent to Paris to be educated. He published several papers on steam engines. He returned to Louisiana in 1834 to work the sugar plantations. In 1846 he patented his vacuum evaporator.

He had problems because of the colour of his skin. He was provided with a special house. However, he could not be entertained in the house of any white man. As the sugar industry was in decline he returned to Paris (around 1854). He did not publish any more material on sugar until 1881 when he was nearly 75.

Norbert died in France in 1894. It has been said that his invention of the sugar process was the greatest in the history of American chemical engineering.

Question 1. How would Norbert Rillieux's life have been different if he had been a white man?

Question 2	Dissolve	Solute	Condense
What do the following words mean?	Soluble	Solution	Crystal
	Insoluble	Saturated	
	Solvent	Evaporate	

Experiment A
Dissolve some sugar in water. Evaporate off most of the water. Leave in a warm place. Do crystals form?

Experiment B
Make up a saturated sugar solution. Warm up the solution so that all the sugar dissolves. Add a sugar crystal and leave to cool.

How to extract sugar in the school laboratory

Method

Preparation of the sugar beet

- Wash the beet and cut off the stem
- Weigh and record its mass
- Chop it up into long thin 'french fries' like pieces

Extraction of the sugar

- Put the sugar beet into a beaker of boiling water
- Gently simmer until it is soft
- Carefully pour off the sugar solution

Purification of the sugar solution

- Heat the liquid to 80 °C
- Add 30 cm^3 of freshly slaked lime (calcium hydroxide)
- Bubble carbon dioxide through the solution until the pH = 11.2
- Filter
- Bubble carbon dioxide through the solution until the pH = 9.0
- Filter under vacuum
- The straw coloured filtrate is called 'Thin juice'

Concentration by vacuum evaporation

- Set up the vacuum evaporator at 40 °C
- Add the thin juice
- Continue to evaporate until the juice has a consistency of thick porridge. This is 'Thick juice'
- Turn off the vacuum

Crystallisation

- Add a little icing sugar and stir slowly
- Wait until crystals have formed
- Filter off the sugar crystals

Questions

Preparation of the sugar beet

1. Why is the sugar beet chopped up?

Extraction of the sugar

2. What happens to the sugar particles when the beet is put in hot water?

Purification of the sugar solution

3. Why is the lime added?
4. The pH of lime is about ______
5. Why does the pH change when carbon dioxide is added?
6. How do you test for pH?

Concentration by vacuum evaporation

7. Why is a vacuum evaporator used?

Crystallisation

8. How do you filter off the crystals?

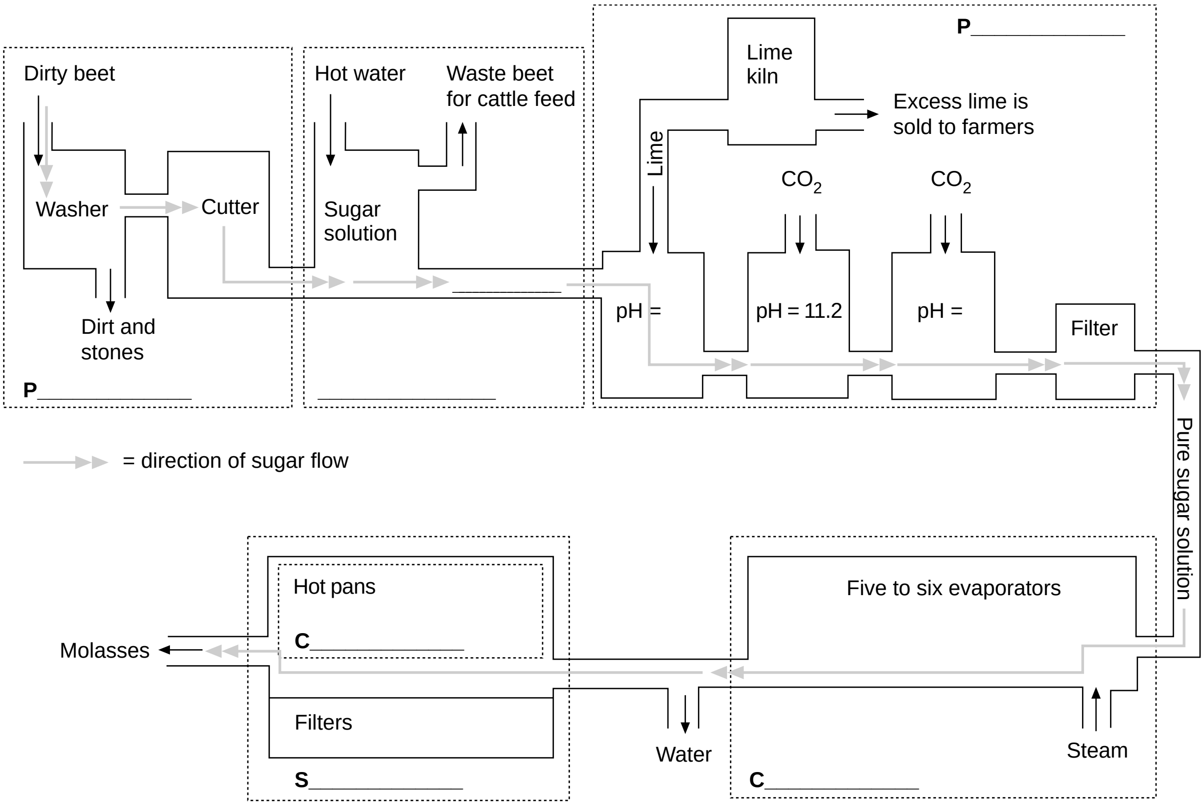
Extracting sugar on an industrial scale

British Sugar extracts sugar from sugar beet. The method is very similar to the one you could use in the school laboratory, but obviously it is done on a much larger scale. At the sugar factory in York, 500 lorry loads of **sugar beet** arrive each day and over 9000 tonnes are processed each day, making about 800 tonnes of sugar. This means that the factory works 24 hours a day, 7 days a week during the sugar beet campaign. The process is **continuous**, until the very last stage, where **crystallisation** takes place in **batches**. The sugar beet factory is very efficient. It has its own lime kiln to produce **milk of lime** and carbon dioxide as well as its own **power station** to provide an energy source to heat the **evaporators**. Any unused electricity is fed into the **national grid**.

The **by-products** from the sugar beet are used to make a high energy animal feed, which is sold to farmers. Excess lime, from the lime-kiln, is also sold to farmers. They use it to **neutralise** acidic soil.

1. Write down the meaning of the words that are in bold in the passage.

The flow chart below shows the journey the sugar beet takes from arrival at the factory to leaving as sugar.



2. Use the following words to fill in the missing labels:

Purification	Preparation	Concentration	Crystallisation
Raw juices	Extraction	Separation	

Mark on the chart where you think the juice will have pHs of about 13 and 9.