Welcome to the British Aerosol Manufacturers Association (BAMA) educational resource about aerosols.

This was produced by BAMA and published on the ASE's School Science website in 2020.

Find out how they are made, how they are filled and how they work. The aerosol industry uses some of the fastest and highest precision equipment in manufacturing today. Its engineers, chemists, materials scientists and designers produce low-cost recyclable products with uses everywhere from the kitchen to the football pitch.

The UK now produces nearly a third of the aerosols in Europe and is second only to the USA in world production. Production has grown dramatically since 1990. About 1.4 billion aerosols are produced each year by companies in Britain and around 50% are exported. UK expertise is recognised all over the world.

This educational resource shows how science is applied in the manufacture and use of aerosols. **It is suitable for students aged 14-19.**

Setup of the resource

Each section has a set of questions and answers provided.

Safety

ASE and BAMA advise against any experiments or demonstrations using full aerosols containing liquified propellants. Accumulation of LPG vapours in a small lab or fume cupboard could cause a fire hazard.

Experiments on flow rates should only be done with bag on valve or bag in can aerosols that use inert gas propellants.

Index

Section 1: Aerosols have many uses

In the home

How many uses are there in the home for aerosols? Deodorants and hairspray are two. Can you find more?

On the farm

What uses can you think of for aerosols on the farm or at the vets. The picture shows a paint marker spray for cattle to show whether they are ready to mate or pregnant.

In medicine

A visit to the chemists will show lots of medical uses. This picture shows an asthma inhaler. This aerosol is unusual because it creates a fine mist made from tiny droplets that can deliver a drug right into the lungs. Normally aerosols make larger droplets to stop this happening. Another feature is that it delivers a measured dose for each press. It has a specially designed valve to do this.

In industry

Industrial uses include cleaner sprays like this one and lubricant sprays.

This is a food grade lubricating spray made from edible oils. Mineral oils are not allowed in food factories because they are toxic.

On the pitch

In World Cup and Premiership matches the referee uses a foaming spray that looks like shaving foam, but is a simple foam that disappears within about thirty seconds; just enough time for a free kick. The defenders must not move over the line.

Photographs: Hassan Ammar/AP

The kick taker can't move the ball either.

At night

Aerosols can spray reflective coatings onto fabrics and even animals. The spray contains transparent micro beads that reflect light back to its source. This is called ***retro reflection.*** Cat's eyes in the road work the same way with large glass spheres. White lines in the road also work the same way. The white paint contains tiny glass beads that are retro reflective.

Retro reflective coatings can be sprayed onto animals to avoid road accidents.

Images: Albedo100

In the kitchen

Aerosol sprays for olive oil allow for use of very small amounts.
The can keeps light and air away from the oil to help preserve it.

In food aerosols the product (olive oil) and the propellant (in this case compressed nitrogen) are kept separate by a bag inside the can.

You can find out more about this in section 4.

Image: Lindal

At sea

For small boats this aerosol horn can be heard a mile away.

Image: Falcon

Questions

1. Make a list of the products that can be delivered by aerosols. Are there any of these that would be difficult or wasteful to use in another type of container?

2. What advantages does an aerosol have for the lubricant spray in the food factory?

Answers

1.There are over 2000 aerosol products on sale, but here are just some:
Oil, cooking oil, dry shampoo (rice starch), hairspray (resins), antiperspirant (aluminium compounds), polish (wax in a solvent), antiseptics, insecticides, paint, dye, air freshener, cleaners (solvents and detergents), ski wax, glues, fungicides,animal markers,whipped cream, mustard..... Did you get more?

2. Edible oils will be attacked by microbes, oxygen and light. The oil would go rancid in an open container and then transfer contaminants and microbes in the factory. The aerosol keeps the oil "hermetically sealed". This means airtight. The one way valve means nothing can get into the can.

History

The first aerosol can that is similar to modern cans was made in Norway by an engineer called Erik Rotheim back in 1929. In 1998 the Norwegian postal service issued a stamp to commemorate it. You can just see the 1929 date on the stamp.

The first cans were heavy and almost completely hand made. Today's cans use steel sheets less than 0.2 mm thick or aluminium made on high speed automatic machines. 1,400,000,000 (1.4 billion) cans are made each year in the UK alone.

Erik's first product was an aerosol wax for skis. He might have been happy to know that the latest high tech aerosol is doing the same job.

Erik did not make any money from his invention and sold the patent. The aerosol became popular in America in the 1940s and 1950s and the rest is history.

UK Success

The UK is the biggest aerosol maker in Europe and exports half of the 1.4 billion cans made here each year. The industry employs 5000 people directly and many more in support industries.

Recycling

Today empty aerosols can be recycled in your green bin. The steel and aluminium recovered has a very high value and uses less energy to process into metal products than new metal made from mined ores. The aluminium in aerosols is especially pure and valuable. Always empty aerosols before recycling.

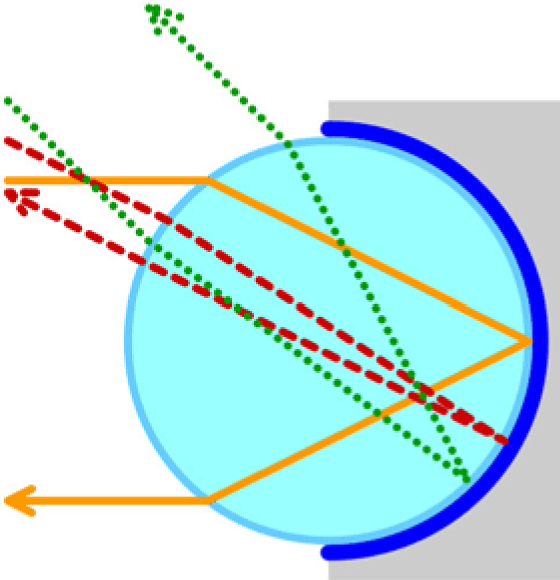


Image: Wikipedia

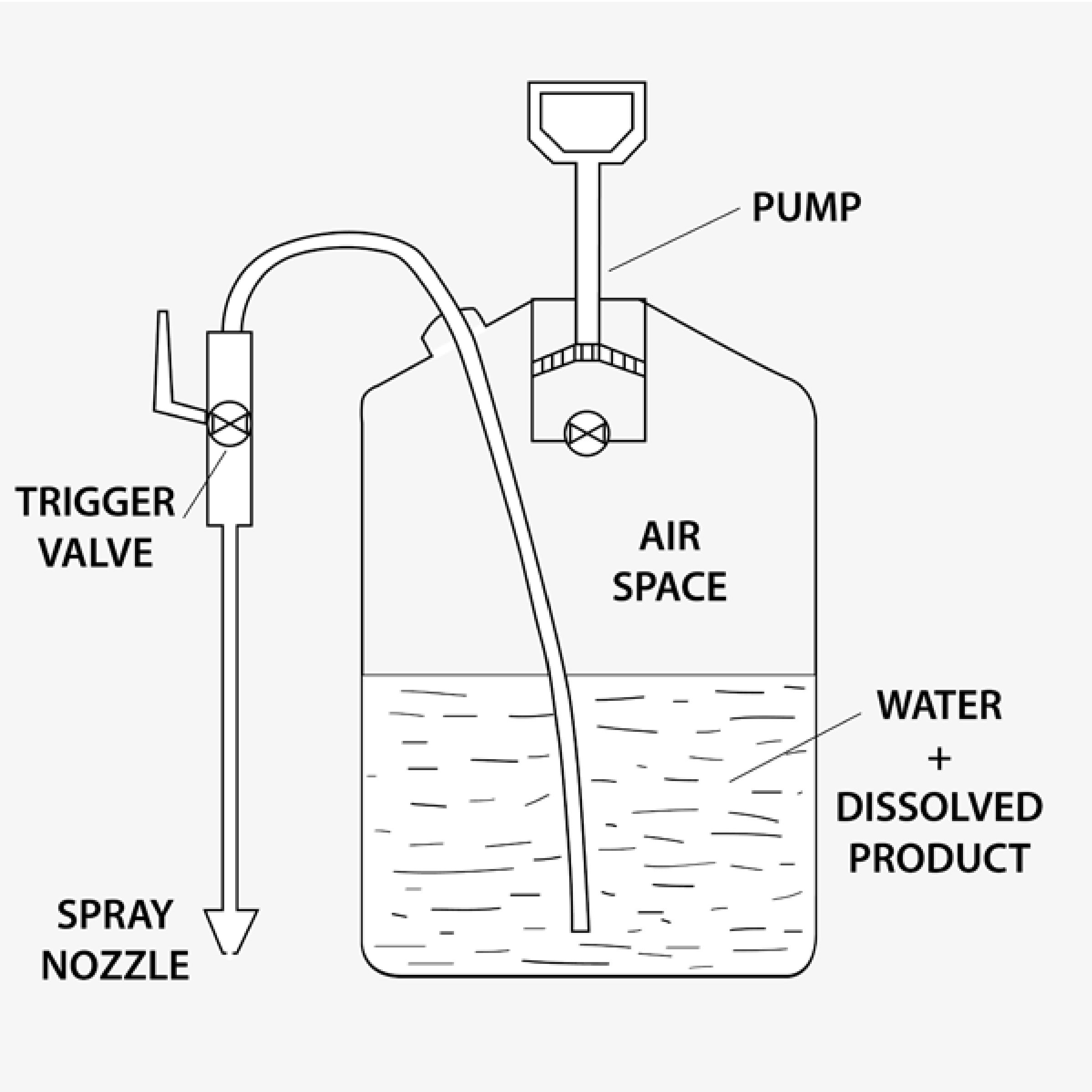
The optics of retro reflection in a sphere. Light coming into the sphere is refracted (bent) on the way in and internally reflected. It leaves in the same direction as it came in. On the road it means that the light reflects straight back to the driver.

SECTION 2: How does an aerosol work?

Let's look at a pump spray bottle first

To compress the air in the pump spray bottle you use mechanical energy to force in more air. Pumping more air into a fixed space increases the pressure.
Once the pressure is above atmospheric pressure it will force the liquid out through the trigger valve.

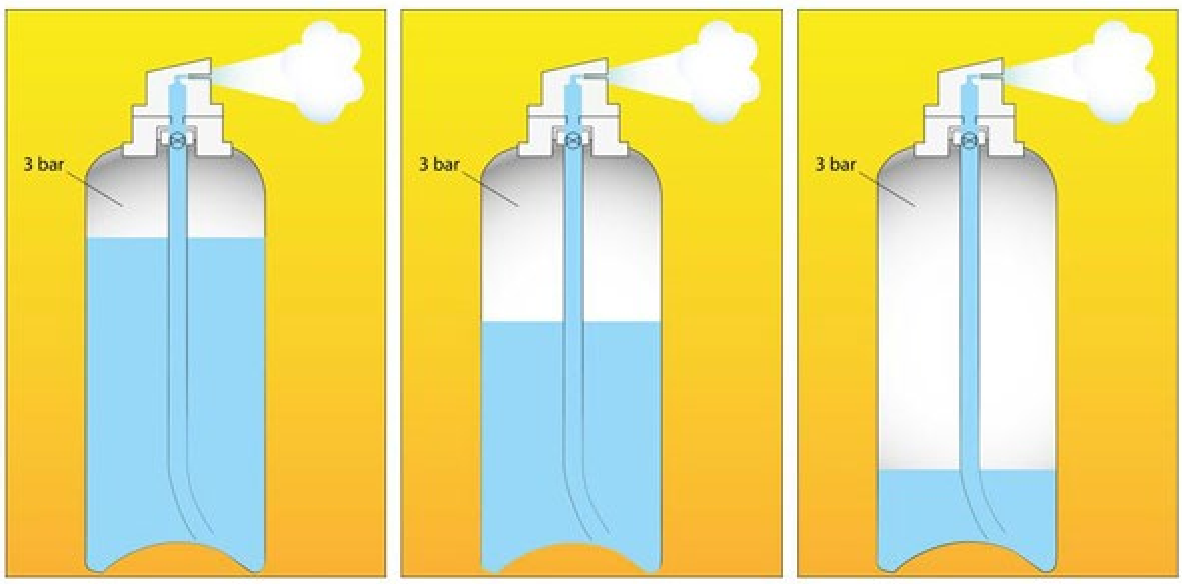
When you stop pumping the trapped air obeys Boyle's Law. As the volume of the air space increases, the pressure drops.
The only way to increase the pressure is to pump more air in.



Now let's look at liquified propellant aerosols

This aerosol can has no pump. As it gets emptier the gas space above the liquid gets bigger, but the pressure does not drop. How is this done?
The reason is that the liquid is not water. It is a liquid that is ABOVE its boiling point at normal room temperature. The space above the liquid fills with vapour because the liquid is trying to boil.
When you boil a kettle you can see that there is a lot of energy driving steam from the spout. This energy comes from the heat put into the kettle. It is hard to imagine, but the same thing is happening in an aerosol at 20ºC because the liquid inside is many degrees above its boiling point.

Keeping the pressure constant



As the product is used the liquid propellant evaporates to fill the space and keep the pressure at three bar.

(NB see APPENDIX at end of document for 'Help with Pressure')

The evaporation is driven by the heat energy in the room and your hand. When you shake or use an aerosol you can feel it cool rapidly.

Can you find some liquids that might be suitable from this table? Remember that at 20 ºC (room temperature) the liquid you choose should not be too far above its boiling point or things could get dangerous!

Liquid	Boiling Point
Water	+100 °C
Butane	-0.5 °C
Propane	-42 °C
Pentane	+35 °C
Methane	-161 °C

Questions

1. Which two liquids in the table might be suitable for use as the propellant in aerosols?

2. Is it the gas or liquid in an aerosol that exerts pressure?

3 Would water work as a propellant in an aerosol?

4. Apart from being a propellant, which other job must an aerosol liquid do?

5. Where would an aerosol with butane propellant stop working?

Answers

1. Butane and Propane are above their boiling points, but not too far. These are the most common propellants in aerosols.

Methane is too far above its boiling point. At 20ºC it would exert a pressure of 70 bar in the can. This would burst normal cans.

Pentane has a boiling point close to human body temperature. It would exert almost no vapour pressure at 20ºC.

2. Molecules in a liquid are held closely together. Molecules in the vapour are moving freely and very fast. They exert a pressure inside the can. Where a liquid is trapped in a can like this the vapour above it exerts a pressure called a vapour pressure. The vapour pressure increases with temperature because the vapour molecules have more energy. The pressure is being driven by the molecular energy driving the change of phase from liquid to gas.

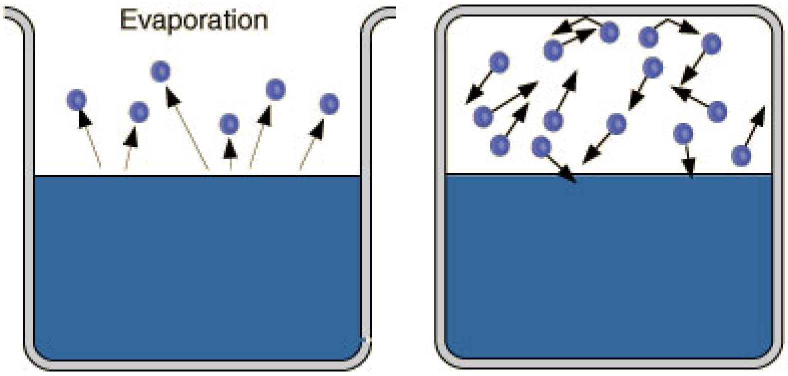


Image: Hyperphysics

3. At 20ºC water vapour exerts almost no vapour pressure. Water would only work if we lived on a planet that had a room temperature of about 120 ºC.

4. The propellant liquid in an aerosol provides the vapour pressure to force liquid out through the nozzle, but an aerosol has to have a useful product in it. The liquid also has to carry the product, either by dissolving it or holding it in a suspension.

5. Butane boils at -2 ºC. If it was outside in winter at below that temperature, the vapour pressure would drop to almost zero and the aerosol would not work. Aerosols that are expected to be kept in cold places like a garage or shed will used a compressed gas like nitrogen as a propellant, not a liquified gas.

Compressed air pump spray bottle

These bottles are used for spraying weedkiller or insecticide dissolved in water. The pump compresses the air in the space above the water. The high air pressure forces the water up the dip tube and through the spray nozzle. As the air space gets bigger the pressure drops and you need to pump more to increase the pressure again. Super Soaker water pistols work in the same way.

SECTION 3: Getting the right vapour pressure

Getting the right vapour pressure

The picture below is the ingredients list for a dry shampoo aerosol. It contains a blend of three liquid propellants that are all above their boiling points at 20 ºC.

The propellant is a mixture of three liquified gases: butane, isobutane and propane. Chemical engineers blend the liquids to get exactly the right pressure in the can.

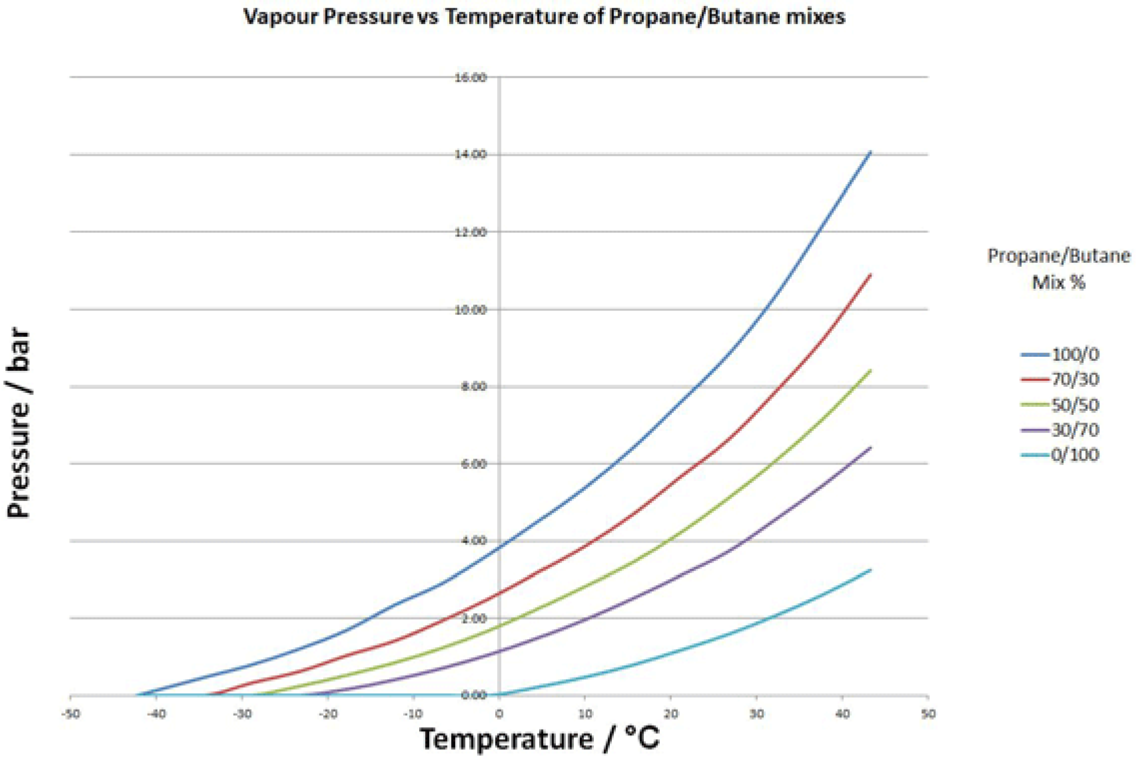
If just single propellants were used the vapour pressure at 20 ºC would be:

PROPANE   8 bar (That is 8 x atmospheric pressure, which is too high)

BUTANE   2 bar (Too low)

ISOBUTANE 3 bar (Too low)

By blending the propellants a pressure that is just right can be created. The higher the propane content, the higher the pressure.



This chart shows how the vapour pressure depends on temperature. The higher the percentage of propane the higher the pressure.

(NB see APPENDIX at end of document for 'Help with Pressure')

The other ingredients are perfumes, alcohol (as a solvent) and conditioners. The iron oxide ingredients are pigments to add a dark brown colour.

Try to find the same information about temperature and propellants on this can. This is an anti-perspirant product. The ingredients are different to the dry shampoo.
The propellants are the same, but the percentage of each will depend on the pressure required by the design engineers.

Storing the liquid propellants

The liquified gases are stored in strong tanks like these. These are kept away from the aerosol filling building. The tanks have safety systems to detect gas leaks and automatic spray systems to prevent fire.

Questions

1. Why are the storage tanks painted white?

2. Why is propane added to the blend of propellants?

3. From the graph what is the vapour pressure of pure butane at 0ºC

4. Which of these statements is true about the graph?
    a. The graph shows a linear relationship between temperature and pressure.
    b. The graph is non-linear. The rate of pressure increase rises with temperature.

5. Compare the pressure increase for 100% propane (the top line) from 10 to 20 ºC and from 30 to 40 ºC.

6. For a 50/50 mix (the green line,) what would you recommend to can designers as the maximum safe working pressure for the can at 50 ºC

ANSWERS

1. White paint reflects sunlight to prevent overheating.

2. Propane has a high vapour pressure. Butane has a low vapour pressure. By mixing the two the ideal pressure can be set.

3. At 0 ºC butane exerts almost no vapour pressure.

4. b is true. The gradient of the lines increases with temperature. This shows that as the gas gets hotter the pressure increase for each degree rise is higher.

5. From 10 to 20 ºC the rise is about 2 bar and from 30 to 40 ºC the rise is about 3 bar.

6. You need to extrapolate the line to estimate the pressure at 50 ºC. My estimate is just over 10 bar. To design in a safety margin I would recommend 15 bar.

When wet is dry

For dry shampoo and deodorants the product is partly dry. Rice starch dissolved in water would turn into a gooey mess like wallpaper paste. The rice starch and powder iron oxide colourings are held in suspension in the propellant, but stay 'dry' because the propellant contains no water.
Cans like this must be shaken vigorously before each use to mix the product into the propellant.

Some of the ingredients DISSOLVE in the propellant. Others are held in SUSPENSION. Products in suspension will eventually settle if they have a density higher than the propellant. Shaking the can before each use mixes the ingredients again.

SECTION 4: Using an inert ideal gas as a propellant

Using an Inert Ideal Gas as a Propellant

An **ideal gas** is one that obeys the ideal gas laws. On this page we will be seeing how nitrogen obeys the Pressure Law and Boyle's Law.

The gas laws only work for A FIXED MASS OF GAS. In these aerosol designs the gas never leaves the can, so the gas laws work.

Inert gases are chemically unreactive. Nitrogen is an inert gas that makes up almost 80% of air.

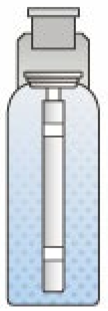
Liquified gas propellants like butane and propane create a constant vapour pressure so that the pressure inside the can never drops until all the liquid has gone. As propellant vapour escapes from the can, more liquid propellant evaporates to replace it. It is this evaporation that creates the vapour pressure.

One solution for ideal gases is a technology called ***bag on valve*** and the use of compressed gases like nitrogen as propellants.
Bag on valve keeps the propellant separated from the product. The propellant does not leave the can; it just squeezes the bag like squeezing a tube of toothpaste. As there is no vapour pressure, the gas pressure will drop as the bag empties. If the starting pressure is high enough, there will still be enough pressure to completely empty the bag.

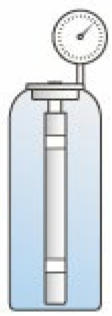
Assembly stages for a Bag on Valve can

1. Rolled up bag on valve assembly drops into the empty can.

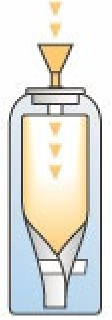
2. An ideal gas (in this case nitrogen) is injected into the space around the rolled up bag at about 2 bar pressure.



3. The pressure is checked. If it is too low the can is thrown out before wasting product by filling it.



4. The product is forced into the bag through the valve The holding tapes break and the bag fills up. This reduces the volume of the trapped nitrogen and so the pressure goes up to about 5 bar. This is an example of **Boyle's Law** in action.



5. Actuator and cap fitted. Ready to use.

(NB see APPENDIX at end of document for ‘Help with Pressure’)

Gloopy products

For viscous products such as shaving gel it would be impossible to fill the can through the valve.

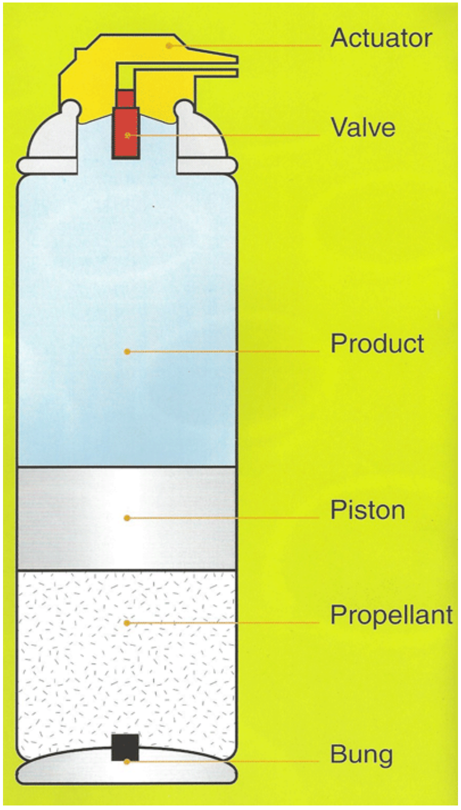
An inner bag is filled with gel before the valve is fitted. This leaves the problem of how to fill the propellant at high pressure.

The only way is through the bottom of the can. A special base design has a rubber bung in the centre. Propellant is injected through a fine needle. The bung then self seals.

Bag in can design for shaving gel. Image: Crown Holdings

Using an ideal gas propellant means the initial filling pressure has to be much higher. The bag is already full when the propellant is injected through the bung. As the product is used up the pressure will drop. To get all the product out the starting pressure has to be around 12 bar.

Even gloopier products!



Some very viscous products including gels, grease and glue are filled directly into the can. A piston in the can is used to push the product out. The propellant is filled through a bung in the bottom of the can.

Boyle's Law applies again as this is a fixed mass of gas that does not leave the can.

As the product is used up, the piston goes up. The propellant volume increases so the pressure drops.

The filling pressure has to be high to make sure the piston makes it to the top of the can.

The propellants in these cans is usually nitrogen or compressed air, depending on the product.

The piston design makes sure that the high pressure gas does not leak around the side.


Image: Ultramotive

The piston is designed to be gas tight in the can.

Questions

1. What is an inert gas?

2. Why is nitrogen used when air would also work?

3. At stage 2 the nitrogen pressure is 2 bar. It fills most of the can. What will happen to the pressure of the nitrogen when the bag is filled with the product at stage 4?

4. The can has a diameter of 4.5 cm and is 10cm high. If the nitrogen pressure is 2 bar at stage 2 and the space left for the nitrogen is only 40cm^3 once the bag is filled, what will be the pressure when the bag is full?

5. What will be the pressure in the can when all the product has gone?

6. What two factors affect the pressure inside a bag on valve aerosol?

Answers

1. An inert gas is one that will not react chemically with with anything. Nitrogen is an inert gas. Other inert gases are the noble gases such as argon and helium.

2. Air contains oxygen that could react with the product, the can, or the bag over time.

3. The volume left for the nitrogen is decreased. So we have the same mass of gas squeezed into a smaller space. The pressure will go up.

4. This question is asking about changes in volume, V and pressure, P for an ideal gas. The temperature is constant. The Gas Law we need is Boyle's Law:

$P_1V_1 = P_2V_2$

V_1 is the volume of the cylinder. We can ignore the volume of the empty bag.

$V_1 = \pi r^2 h = 3.142 \times 2.25^2 \times 10\ cm^3 = 160\ cm^3$

If the space between the bag and the can is reduced to 40 cm^3 after filling, then the pressure P_2 will be

$P_2 = P_1 \times V_1/V_2$

$P_2 = 2 \times 160/40 = 8$ bar

5. When all the product has gone the pressure will return to 2 bar. The nitrogen behaves like a compressed spring forcing the product out of the bag.

6. The volume of the nitrogen around the bag is the biggest factor. The temperature of the can is the second factor. In normal household use the temperature will vary between about 5 and 20 degrees. Cans are tested during manufacture to the pressure experienced at 50 ºC.

Close up of the label of a Sterimar salt water nasal spray can. Can you identify the propellant used?

This cutaway section shows how the rolled up bag is filled inside the can. The white holding tape is weak enough to break as the bag is filled.
You can see that the volume of the nitrogen propellant is reduced from almost the whole can down to just a small fraction of the can. According to Boyle's Law the pressure has to rise as the nitrogen is squeezed into a smaller volume.

Image: Birkbeck College

The table printed below is from Boyle's original experimental data.
In thofe dayf the preffure of the atmofphere was fpelled differently!

A table of the condenſation of the air.

A	A	B	C	D	E
48	12	00	Added to $29\frac{1}{8}$ makes	$29\frac{2}{16}$	$29\frac{2}{16}$
46	$11\frac{1}{2}$	$01\frac{7}{16}$		$30\frac{9}{16}$	$33\frac{6}{16}$
44	11	$02\frac{13}{16}$		$31\frac{15}{16}$	$31\frac{12}{16}$
42	$10\frac{1}{2}$	$04\frac{6}{16}$		$33\frac{8}{16}$	$33\frac{1}{7}$
40	10	$06\frac{3}{16}$		$35\frac{5}{16}$	35- -
38	$9\frac{1}{2}$	$07\frac{14}{16}$		37	$36\frac{15}{19}$
36	9	$10\frac{2}{16}$		$39\frac{5}{16}$	$38\frac{7}{8}$
34	$8\frac{1}{2}$	$12\frac{8}{16}$		$41\frac{10}{16}$	$41\frac{2}{17}$
32	8	$15\frac{1}{16}$		$44\frac{3}{16}$	$43\frac{11}{16}$
30	$7\frac{1}{2}$	$17\frac{15}{16}$		$47\frac{1}{16}$	$46\frac{3}{5}$
28	7	$21\frac{3}{16}$		$50\frac{5}{16}$	50- -
26	$6\frac{1}{2}$	$25\frac{3}{16}$		$54\frac{5}{16}$	$53\frac{10}{13}$
24	6	$29\frac{11}{16}$		$58\frac{13}{16}$	$58\frac{2}{8}$
23	$5\frac{3}{4}$	$32\frac{3}{16}$		$61\frac{5}{16}$	$60\frac{18}{23}$
22	$5\frac{1}{2}$	$34\frac{15}{16}$		$64\frac{1}{16}$	$63\frac{6}{11}$
21	$5\frac{1}{4}$	$37\frac{15}{16}$		$67\frac{1}{16}$	$66\frac{4}{7}$
20	5	$41\frac{9}{16}$		$70\frac{11}{16}$	70- -
19	$4\frac{3}{4}$	45- -		$74\frac{2}{16}$	$73\frac{11}{19}$
18	$4\frac{1}{2}$	$48\frac{12}{16}$		$77\frac{14}{16}$	$77\frac{2}{3}$
17	$4\frac{1}{4}$	$53\frac{11}{16}$		$82\frac{12}{16}$	$82\frac{4}{17}$
16	4	$58\frac{2}{16}$		$87\frac{14}{16}$	$87\frac{3}{8}$
15	$3\frac{3}{4}$	$63\frac{15}{16}$		$93\frac{1}{16}$	$93\frac{1}{5}$
14	$3\frac{1}{2}$	$71\frac{5}{16}$		$100\frac{7}{16}$	$99\frac{6}{7}$
13	$3\frac{1}{4}$	$78\frac{11}{16}$		$107\frac{13}{16}$	$107\frac{7}{13}$
12	3	$88\frac{7}{16}$		$117\frac{9}{16}$	$116\frac{4}{8}$

AA. The number of equal ſpaces in the ſhorter leg, that contained the ſame parcel of air diverſly extended.

B. The height of the mercurial cylinder in the longer leg, that compreſſed the air into thoſe dimenſions.

C. The height of the mercurial cylinder, that counterbalanced the preſſure of the atmoſphere.

D. The aggregate of the two laſt columns *B* and *C*, exhibiting the preſſure ſuſtained by the included air.

E. What that preſſure ſhould be according to the hypotheſis, that ſuppoſes the preſſures and expanſions to be in reciprocal proportion.

Boyle's figures are in inches with fractions. Decimals were not commonly used then. In his experiment he used mercury to compress air trapped in a tube.

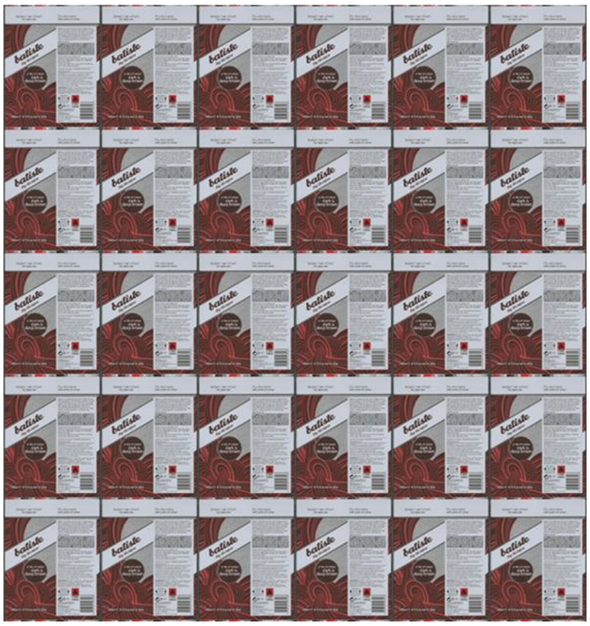
You can use this Excel spreadsheet file to make charts using Boyle's original data (downloadable from the main web page: **Boyle's-decimalised original data.xlsx**)

SECTION 5: Making steel and aluminium aerosol cans

High speed precision engineering

Image: Thyssen-Krupp

Tin plated steel arrives in coils from the steelworks. Each one is about 4km long and a metre wide.
A colour printing press prints the can graphics directly onto the steel sheet before the sheet is slit and chopped to smaller sheets for bending into the can cylinders.



This sheet is slit and then chopped into rectangles for each can.

Welding the seam

The diagrams on the right show the can welding process. Two copper electrodes roll alond the seen. A large electric current passes between the elctrodes and melts the two peices of steel together.

If you want to see really fast can welding, look at the videos on this site. (Serious speed freaks only)

It is at the actual speed of ~400 cans/minute, and shows flat sheets of tinplate steel that get rolled in a cylinder and welded. It's a smooth flowing process that takes place within a single piece of equipment.

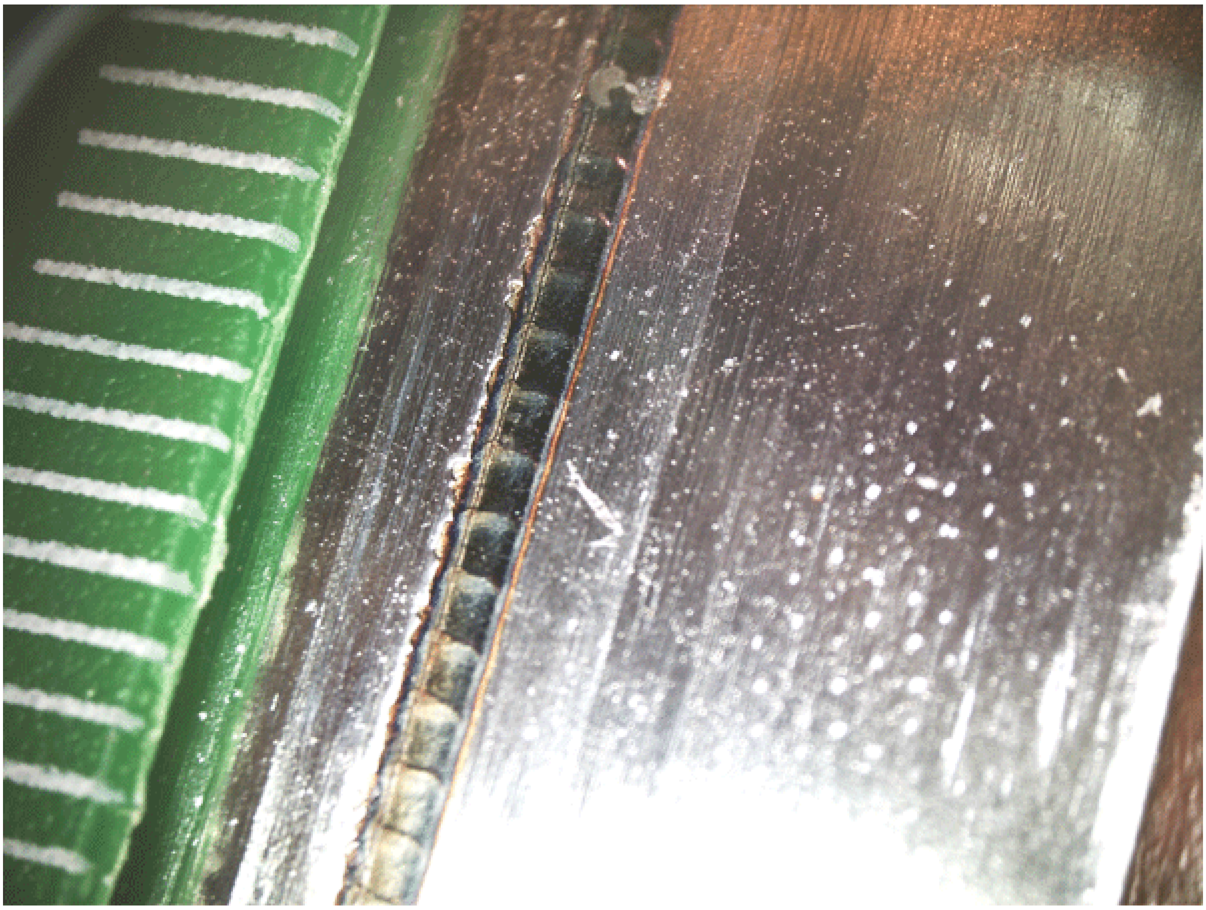
https://www.youtube.com/watch?v=kCt2w8Jlcb4

To see a video showing valve insertion, positioning and crimping, click on the link below. It shows a close ip of the process from 45 seconds onwards

https://www.youtube.com/watch?v=5xDKigJ2pV0

To see a video showing different types of tinplate cans and how they are made:
https://youtu.be/ruOGOLVA078

If we look at a seam using a USB microscope or a low power binocular microscope we can see that the seam has a regular pattern. This is caused by pulsing of the welding current. The weld is not a continuous line, but a series of overlapping "nuggets". The timing of the pulses and the speed of the cans has to be precisely controlled. If the cans go too fast there will be gaps and the can will leak. If it goes too slowly, the heat will melt a hole in the can. The green strip is the edge of a plastic ruler marked in mm.



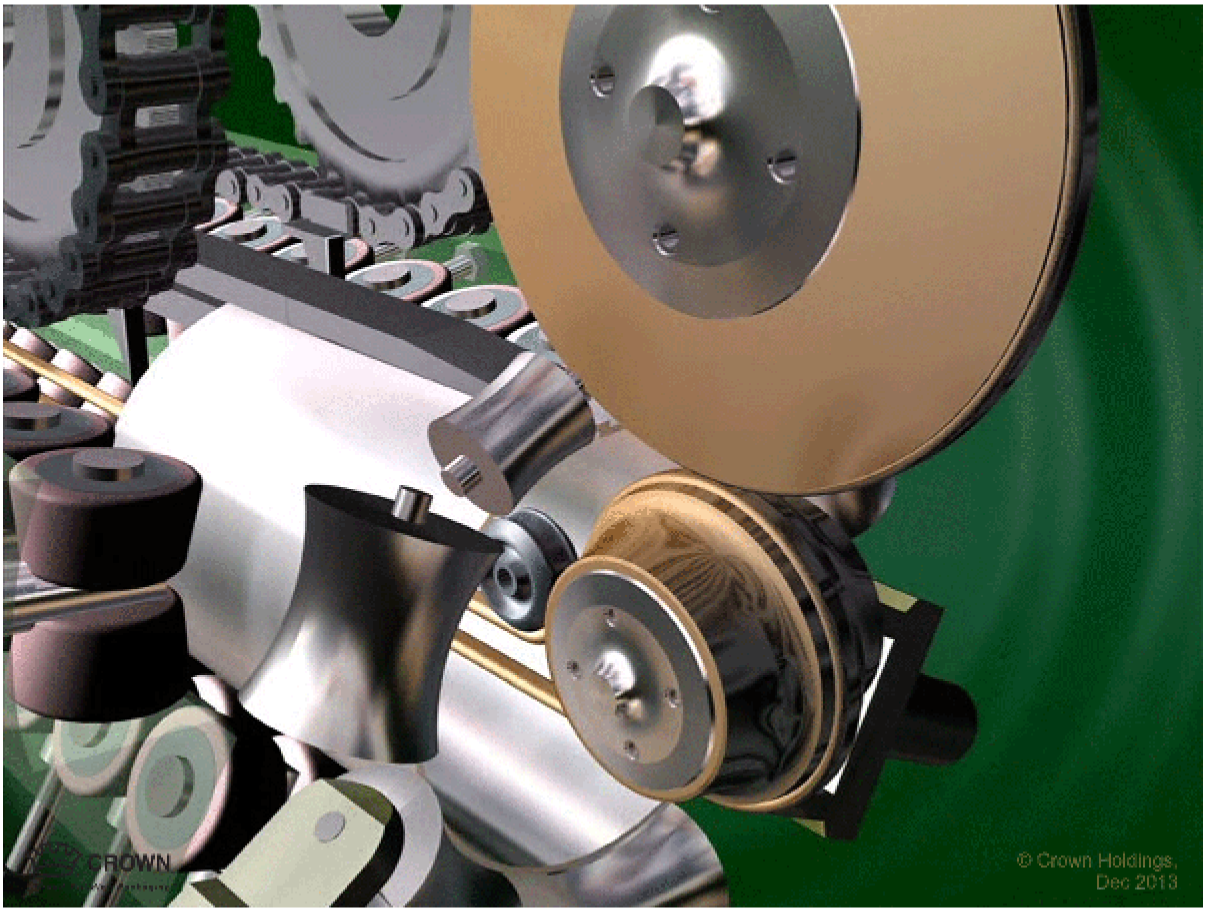
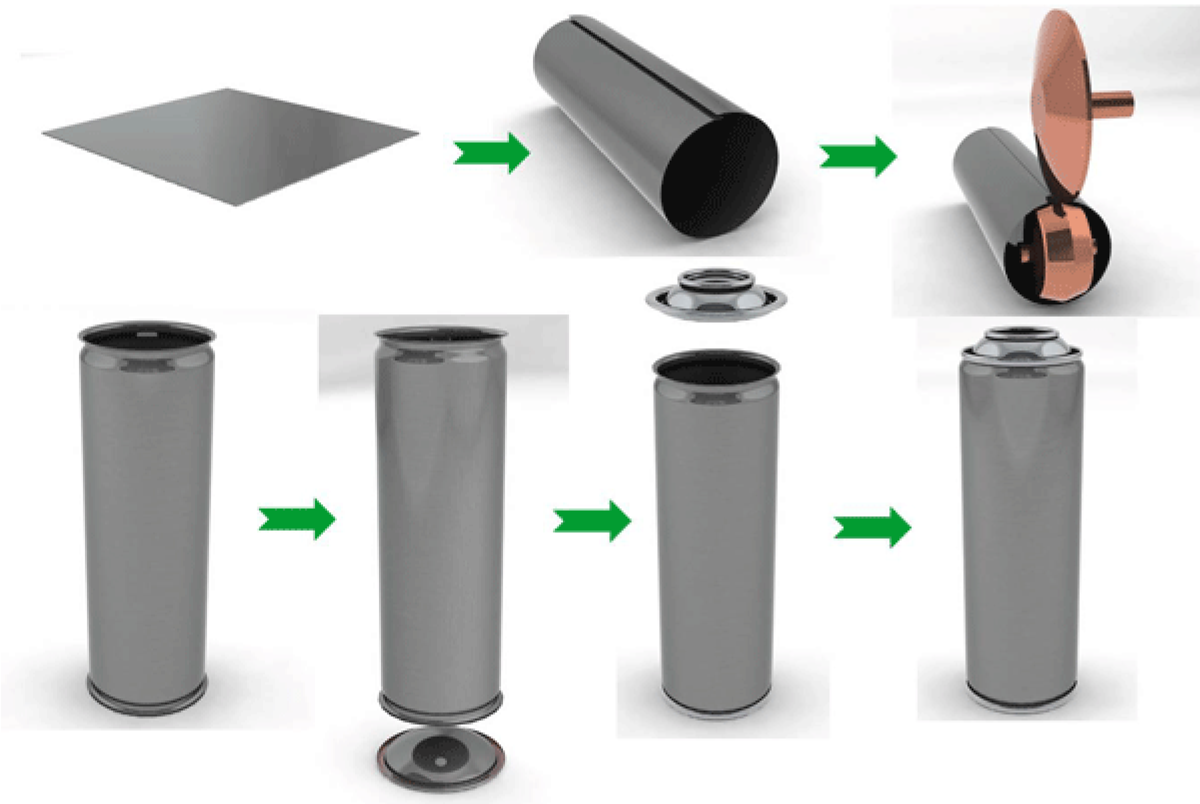

CROWN
© Crown Holdings,
Dec 2013

Image: Crown Holdings

In the pictures above and right try to identify:

1. the slightly overlapping can edges
2. the copper electrode wire around each wheel
3. The forming rollers that bend the can into shape

The final process is to add the top (cone) and bottom (dome)



Questions and Activities about steel cans

1. Either from the microscope view above or using your own USB microscope and a mm scale work out the pulse frequency of the weld current if the can seam is is 20 cm long and moves through the welder in 0.5 s.

2. Why does the printing on the can stop few millimetres from the seam line?

3. Why is copper used for the electrode wheels and the wire in the welding machines?

Answers

1. Each nugget is the result of one pulse of current. The nuggets are 1mm apart. The speed is 40 cms^{-1} or 400 mms^{-1}. This is 400 nuggets per second, so the pulse frequency is 400 Hz.

2. The printing inks and varnishes are insulators. They would stop the current flowing through the steel sheet.

3. Copper is a very good conductor of electricity. It can take high currents without getting too hot.

Making aluminium cans

About half the cans made in the UK are aluminium. They are lighter, they have no seam, and smaller cans can be made.

The manufacturing process involves forming a can from a single slug of aluminium using a punch and die at huge pressure. Aluminium is a soft metal. When it is subjected to the huge forces of the punch it heats up and flows like a liquid.

To see the process of aluminium can extrusion, click on the link to the video below:
https://www.youtube.com/watch?v=-xhwrnGkjas

Questions about aluminium aerosol cans

1. Why is the extrusion process used for aluminium cans not suitable for steel cans?

2, What is the difference between the printing process between aluminium cans and steel cans?

Answers

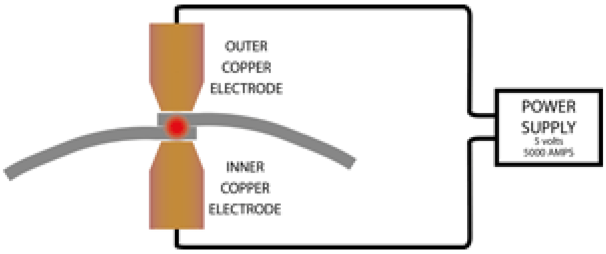
1. Steel a harder metal. It cannot be extruded from a cold slug. Steel can be stamped and punched, but it will not flow into a long can shape.

2. Steel cans are printed as a flat sheet before cutting. Aluminium cans are printed when they are cylindrical. The shaping of the top of the can is done after printing.

How do you turn a flat sheet of steel into a cylinder with a leak proof seam?

This is a close up of the seam.

The solution is to weld the sheet edges together using electric current, as shown the the diagram below.. Two electrodes press against the steel, one from outside and one from inside. The electrodes are connected to a power supply that drives a huge current of up to 5000 Amps through the metal. This melts the two overlapping layers together. This is called **resistive welding.** The current is pulsed at high frequency, one pulse for each spot or 'nugget' on the weld.



To make a long seam the electrodes need to be wheels to roll along the can.

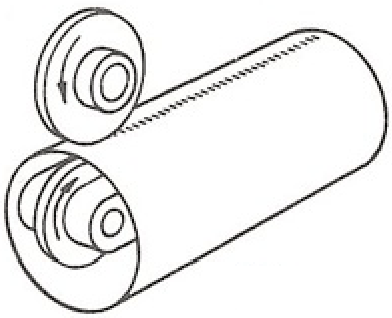


Image: spotweldinc.com

Making the perfect electrode wheel

For a perfect leak-proof welded seam the electrode wheels must also be perfect. After only one turn a copper wheel would pick up blobs of molten metal and be useless. The solution is to run copper wire round the wheels that is never re-used. The copper is recycled and made into new wire so the cost is reduced. You can see the copper wire in the second video.

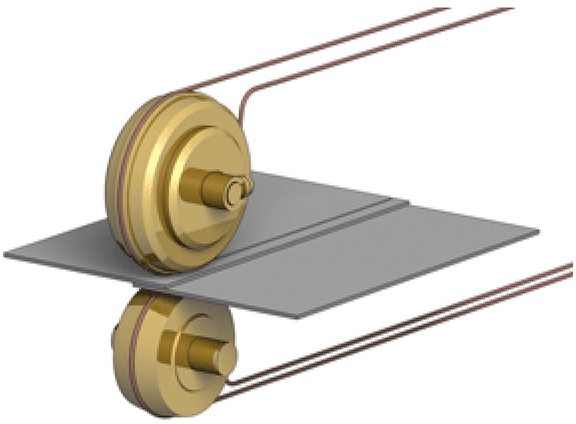


Image: mechanicalengineeringblog.com

The copper wire always presents perfect new electrode surfaces as it is only used once. Getting the inner wheel into the inside of the can is not so easy as the can is moving in one direction. The trick is to curl the can into a cylinder just before it gets to the wheels.

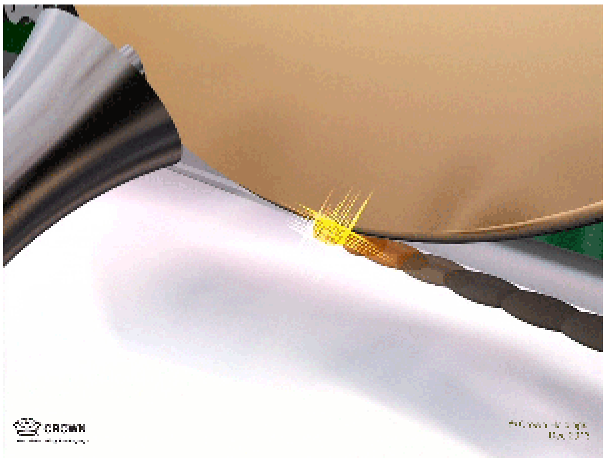


Image: Crown Holdings

Close up of the weld. There is a "nugget" for each pulse of current. The nuggets must just overlap. The slightest gap would cause a leak. Engineers regularly inspect the welds with a microscope.

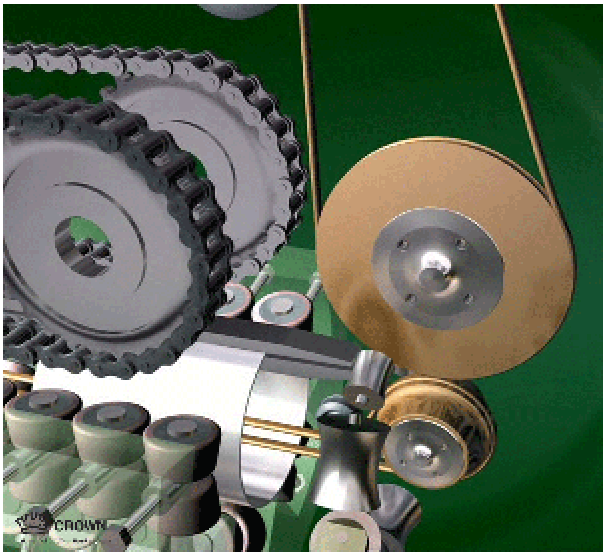


Image: Crown Holdings

A can approaches the wheels from the left. It has just been curved around the inner wire.

Hiding the seam

The seam on steel cans is a problem for can designers. The can is printed when it is flat sheet and then bent and welded. As ink is an insulator it must not cover the seam because it will stop the welding current from flowing though the sheet metal. This leaves an unprintable stripe on the can.

Image: Colep

Engineers have managed to reduce the width of the stripe from 5mm to 1.5mm. Now that you have seen how the seam is made you can see that this is a big precision engineering achievement.

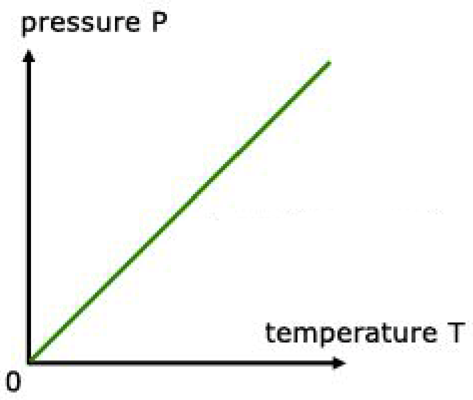
SECTION 6: Water bath leak testing

Water bath leak testing

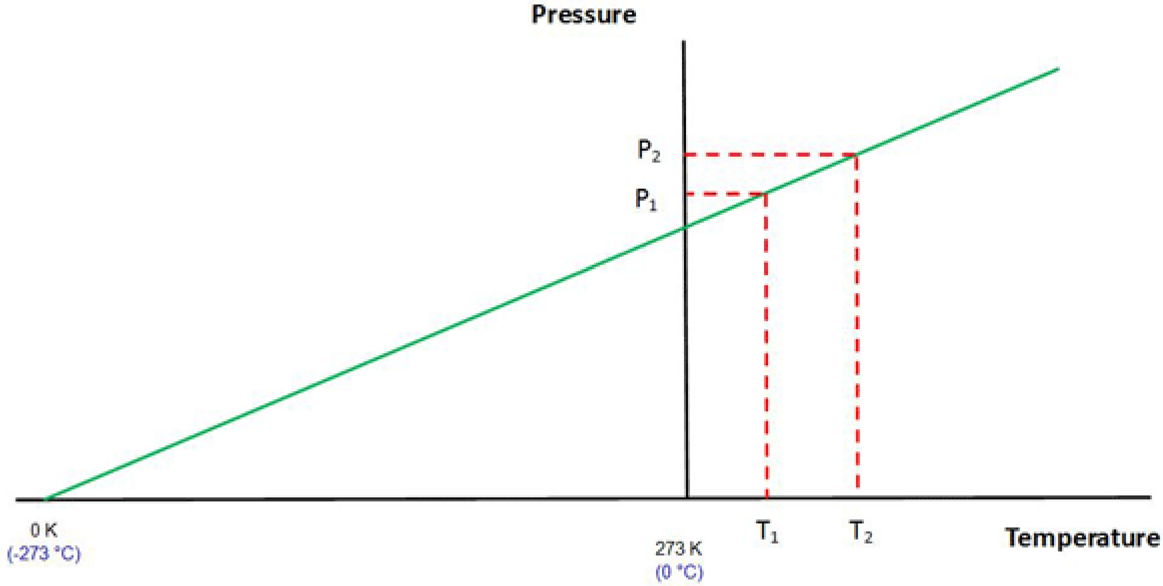
During manufacture most filled aerosols are immersed in a hot water bath at 50 ºC for about three minutes This is 30 ºC above normal room temperature The purpose of this test is to check for leaks at well above the temperature that aerosol cans would be exposed to in normal use.

The increased temperature raises the pressure inside the can. Any can that leaks is detected and rejected.
Where the propellant is a liquified flammable gas, any leak has the potential to be dangerous. The highest risk is during transport, when several thousand cans are tightly packed on a truck.

For an ideal gas the Pressure Law will show how the pressure of a fixed volume of gas will change with temperature.



Before doing any calculations we have to be clear about the zero point on this graph. Zero pressure means zero kinetic energy of the gas molecules. This happens at Absolute Zero (zero Kelvin), the lowest possible temperature. Absolute zero is -273 ºC.
To make this easier to see the graph can be drawn like this:



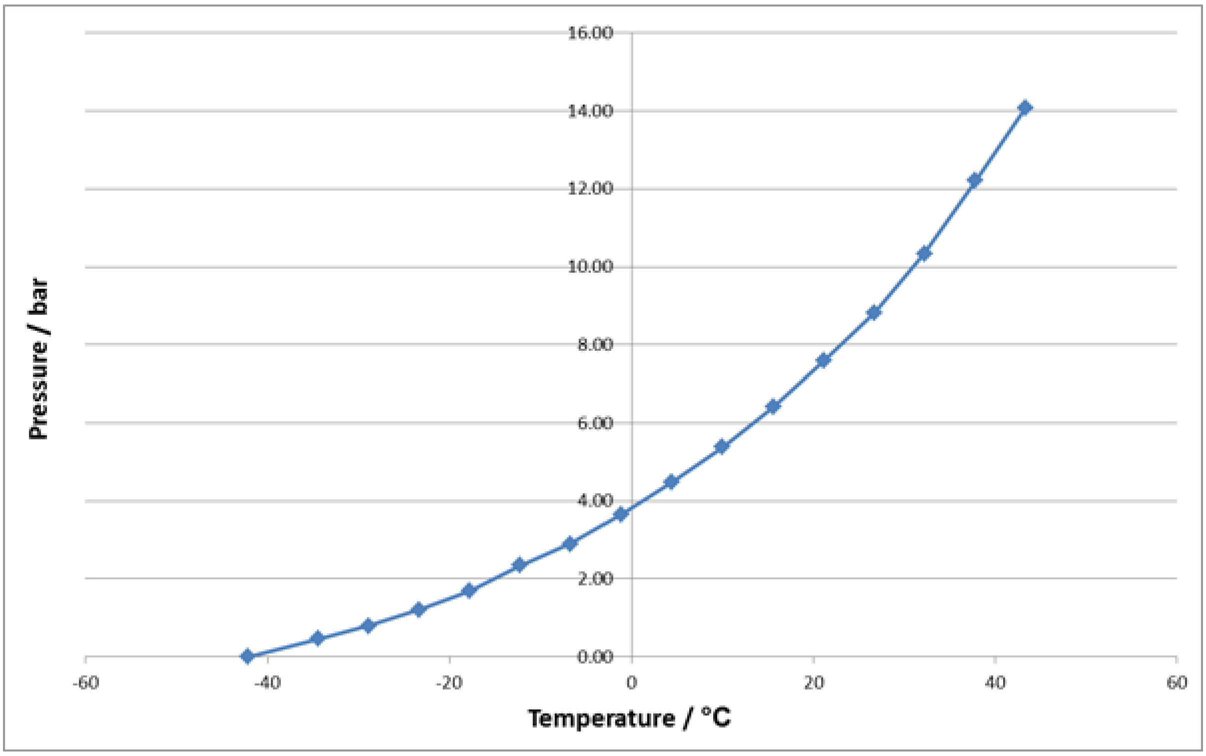
0 ºC is 273 K and so 20 ºC is 293 K.

If T_1 is 20 ºC and T_2 is 50 ºC then the pressure inside the can will rise from P_1 to P_2. As the pressure/temperature line is straight (for an ideal gas) it means that the ratio of P to T is constant. The maths only works if the temperature units are Kelvin.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Does the pressure law work for propane and butane vapour?

The answer is no. The graph of pressure against temperature for propane looks like this:

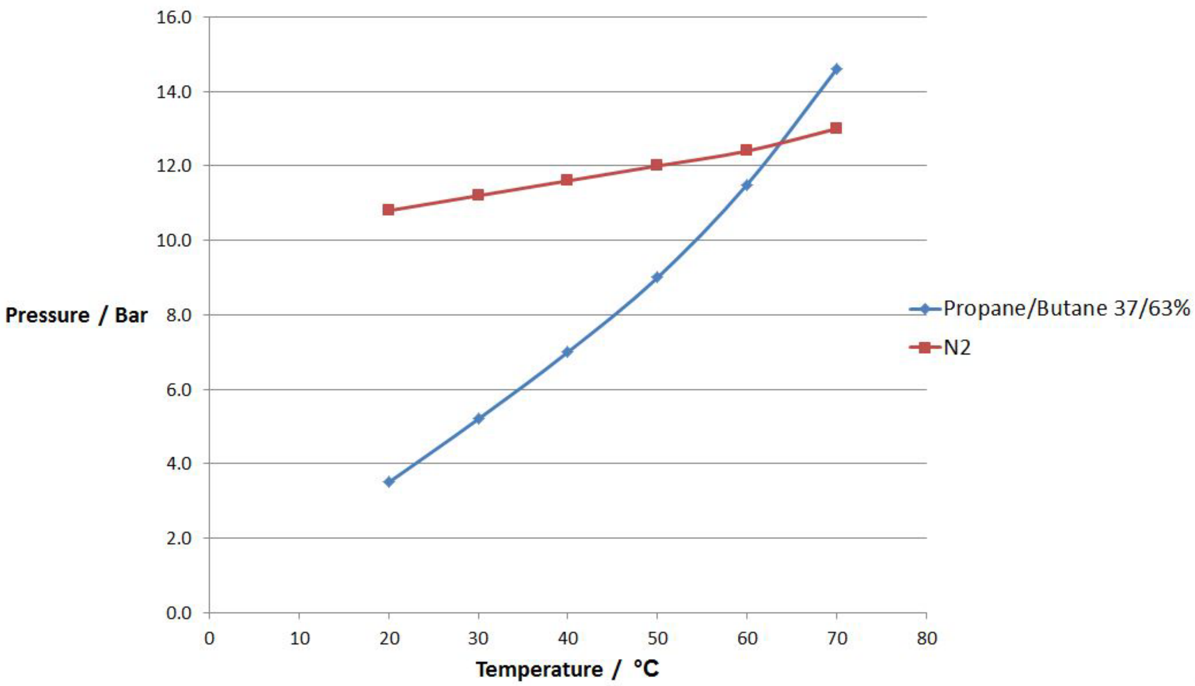


The line stops at -41 ºC because all the propane condenses to liquid below that temperature. The line is not straight so there is no simple ratio of pressure to temperature. As the temperature rises, the pressure increases at a higher rate.

The reason for this is that the evaporation of liquid propane in the can is creating the pressure. This is the same as the evaporation that dives a steam engine, but at a lower temperature.

So a vapour over a liquid does not behave like an ideal gas. Engineers and designers need to know this to make sure cans will withstand higher pressures. The water bath test makes sure potentially dangerous cans are rejected.

Comparing propellants



This chart compares two propellants. Nitrogen (red) and a propane/butane mix (blue) This is real data from a test lab.

Nitrogen is an ideal gas and obeys the pressure law. The line is straight.

The propane/butane mix (blue) has a curved line.

You can download the Excel spreadsheet of the data here to make your own charts. (File can be downloaded from the main page: **Vapour vs gas-data.xlsx)**

(NB see APPENDIX at end of document for 'Help with Pressure')

Questions

1. Why are the cans immersed for 3 minutes and not, say, just a few seconds?

2. Rearrange the equation above to make an expression for P_2. So P_2 = ?

3. What is 0 ^{o}C in Kelvin?

4. What is 50 ^{o}C in Kelvin ?

5. If the initial pressure of a full bag on valve can with nitrogen propellant is 7.5 bar at 20 ºC, what will be the pressure if the can reaches 50 ºC in a water bath?

6. After manufacture, where would the danger of a leaking aerosol propellants be greatest?

7. Fill in the gaps in this table.

°C	K	bar
27		2
	600	
		6
-123		

Answers

1. The can and the contents (propellant and product) have a heat capacity. It takes at least three minutes to raise the temperature of the contents to 50 ºC.

2. $P_2 = P_1 \times T_2 / T_1$ The pressure increase by the ration of temperatures, but ONLY if the temperatures are in Kelvin (ºC + 273)

3. 273 K

4. 50 + 273 = 323 K

5. The first step is to convert ºC to K

T_1 = 20 ºC = 293 K

T_2 = 50 ºC = 323 K

The Pressure Law gives us

$P_2 = P_1 \times T_2 / T_1$

$P_2 = 7.5 \times 323 / 293$

P_2 = 8.27 bar

6. The danger is greatest where the cans are concentrated in one place. This will be on a truck or in a warehouse, which is why special precautions are taken during handling.

7.

°C	K	bar
27	300	2
327	600	4
627	900	6
-123	150	1

Aerosol cans pass through a water bath at 50 °C for three minutes.

The maximum safe temperature for an aerosol is 50 ^{o}C.

Look at the Pressure Law equation. If T_2 is a larger number, then P_2 has to be larger because the ratio P/T is a constant.

Remember that the maths only works when the temperature is in Kelvin. Converting ^{o}C to K is easy. Just add 273!

SECTION 7: Valves and flow control

Filling 1.54 billion aerosol cans a year

In the UK alone, 1.54 billion aerosols are filled each year. Filling is a high speed operation.

Image: Coster

Filling the product

For products that are too viscous to be filled through the valve the product is filled before the valve assembly is added.
Here is a video about the pressurisation process (the propellant is injected in the cans, the pressurised cans are tested for leakage, the 'faulty' ones are automatically rejected from the line):

https://www.youtube.com/watch?v=UbKxbAtOYdk

Liquified propellant filling

Image: Hydrokem

These small green buildings contain the gassing machines that fill aerosols with the propane/butane propellant.
Below is a close up view of a similar filling house.
The walls and roof are designed to come off in the event of a gas explosion.
The gassing houses are outside the main building to protect people inside. Each one is ventilated with powerful extractor fans to take away even the tiniest amounts of propellant vapour.
Gas sensors and fire detectors that sense the smallest flame automatically set off fire extinguishers and shut down the propellant supply.
This technology makes gassing a safe operation.

Leaks after filling

Leaks of propellant vapour from faulty cans can happen after filling. These can be detected in a water bath as bubbles (see page 6).

Some production lines use gas detection equipment that can detect a few parts per million of gas at high speed, without even stopping the conveyor belts. Butane absorbs certain wavelengths of infrared light, so by shining an infrared laser through the gas any absorption will be detected as a drop in the light level by an infrared detector. The laser takes 100,000 samples per second and is so fast that it can trigger an ejector to eject the leaking aerosol from the production line.

Image: Cascade Technologies Ltd.

The image on the right shows the gas sampling arch. Gas is sucked into the holes in the arch at high speed. If the system detects a leak the aerosol is pushed off the production line.The whole process takes less than 1/8th of a second.

Image: Cascade Technologies

Preventing sparks

Even with many safety systems there is still a chance that a spark could start a fire or cause an explosion.

Electrostatic sparks

Wearing synthetic fibres like polyester together with cotton or wool can cause sparks. Workers in aerosol filling plants are not allowed to wear any synthetic fibres. Some companies pay a clothes allowance because cotton products are more expensive.

Electrical switches and motors

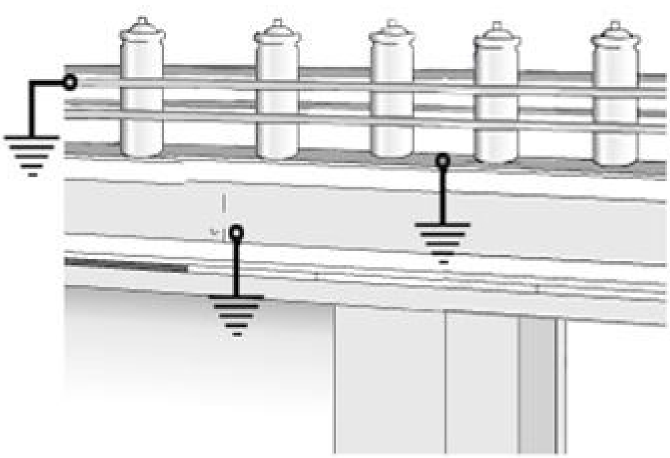
When an electrical switch turns off a motor there can be a sudden high voltage induced in the motor coils.This can cause a spark. There are special 'explosion proof' switches than keep any sparks sealed inside the switch casing and also special motors that do the same.

Conveyor belts

Rubbing plastics together is a good way to make electrostatic sparks. The conveyor belts in aerosol factories are made from plastic containing conductive carbon. Any electrical charge is conducted away to the metal parts of the machinery. Airport baggage carousels use the same conductive plastic for the conveyor belts.

Electrical earthing

Sparks occur when two objects have a different electrical charge.
To prevent sparks all machines are connected to earth.



Questions

1. How many aerosol cans are filled in the UK every second?

2. Why are the propellant gassing houses fitted with loose roofs and wall panels?

3. Why is a gassing machine using nitrogen or CO2 allowed to operate in the main factory building?

4. Where would you put gas sensors in the factory to detect propane and butane?

Answers

1. On average it is around 49 (1,540,000,000 / 365 / 24 / 60 / 60)

   2. If an explosion occurred, the pressure and flame would otherwise be forced into the main building. By letting the roof and doors blow out, the pressure does not rise to dangerous levels.

3. Nitrogen and CO_2 are inert gases. They will not cause an explosion or a fire. The gassing machines can fill nitrogen at up to 16 bar so a protective cabinet is placed around the machine. 16 bar is about five times higher than a car tyre pressure.

4. Propane and butane are heavier than air and any gas will sink to the floor. Sensors are place near the floor for that reason.

SECTION 8: Filling 1.54 billion cans a year

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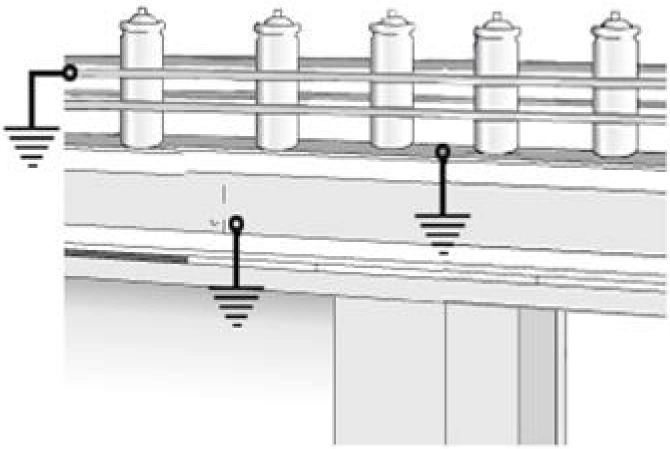

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SECTION 9: Who makes aerosols?

Aerosol manufacturing brings together a huge range of career opportunities. Employers range from small consulting companies to multinational corporations.
Making cans and valves is a high speed precision engineering business and filling them is a high speed chemical engineering business.
Careers start at apprentice level and graduate level. Larger employers have valuable training schemes for apprentices, graduate engineers and business management.

Chemist

Chemists design and test ingredients. There are many ingredients in aerosol sprays and chemists need to understand how they mix or react.

For more on chemistry careers try this website. http://www.rsc.org/careers-jobs/

Chemical Engineer

Chemical engineers understand the processes of mixing and reacting chemicals on a large scale.

For more on chemical engineering careers visit the IChemE website:

https://www.icheme.org/career/

Electrical/Electronic Engineer

Aerosol plants have some of the highest value equipment in industry. This needs planned maintenance, monitoring and testing. Electronics and electrical engineers are in high demand all over the world.

For more on electrical engineering careers try this website: http://www.theiet.org

More about engineering careers

For more information on engineering careers try these websites.

http://www.tomorrowsengineers.org.uk/

Graduate entry case study

Curiosity is the key to unlock a career in Aerosol Technical Management

When Christina Jenkyns completed her Biological Sciences Degree at Plymouth University, she knew she wanted to work in a scientific discipline – but didn't quite know where. After a short stint working for the National Rivers Authority she responded to an advertisement in her local paper in Somerset, to work as a laboratory technician for Swallowfield, a member of the British Aerosol Manufacturers' Association (BAMA).

Christina didn't quite know what to expect from the role, however, she soon realised that she loved everything about the job.
"Even though I was scientifically trained, I had no idea about a career in the aerosol sector when I first qualified. Most existing higher education courses concentrate on cosmetic science and aerosols are only a small part of those courses."
Christina explains that Swallowfield's aerosol department works with high street retailers offering help, direction and support for its customers' brand aspirations. Christina's role as a laboratory technician involved carrying out stability tests, user trials, fragrance tests, laboratory reports and other scientific tasks that contributed towards new product development.

After ten years Christina moved to Reabrook Ltd, also a prominent member of BAMA, specialising in formulations, manufacturing and contract filling of aerosol and liquid products for private label customers.
"I couldn't believe my eyes when I read the job requirements. I was so pleased to find something that looked perfect for me – although it did take me out of my comfort zone as I would be working with not just cosmetic products but more industrial, household and automotive ranges too."

"One of the key requirements besides organisation for my job is curiosity," she explains. "To develop a product from concept to shelf takes patience, as it rarely comes out right the first time, accuracy, and the ability to absorb a mountain of information and regulations is also key. This is where BAMA is so helpful, with their wide range of training courses and keeping us abreast of all the new technical regulations in particular."

The aerosol sector is a specialised field, but Christina goes on to explain how those in the industry are really helpful to share their knowledge and experience. She particularly enjoys working with a variety of disciplines, such as valve producers, aerosol fillers, marketers, producers of component parts, machinery and ingredient suppliers and of course Reabrook's clients who include; Superdrug, Tesco, Marks & Spencer, and Numark.

Christina finds her role very challenging, yet satisfying as she co-ordinates and liaises with a range of external and internal audiences whilst having to keep up to date with industry legislation. "I get quite emotional when I see a new product coming off the line, when I have been involved at concept stage. It gives me a huge sense of satisfaction. I have also been known to jump up and down with excitement when I see a product in-store that I've worked on."

Careers Advice for other female graduates looking to get into the Sector

Christina Jenkyns answers key questions

Why is a Technical Manager in the industry a good job for women?

It uses multitasking and good organisational skills It also helps to even up the balance of men to women that I still think exists in higher management in the aerosol industry.
This job is highly customer facing, as we have close liaison with our customers who are mainly large retailers. This brings us into contact with technical people and buyers in the retail sector,

and women are often very skilled in the “softer” people-skills that are required.

What are the opportunities for career development?

Unfortunately for the companies involved, there are always people moving onto pastures new or retiring from the industry and I think that unless people develop and grow their roles within this sector, there will be some large losses of information, wisdom and experience. Clearly this offers opportunities for advancement.

Are you able to encourage other graduates/women into the sector?

Yes, very much so. Reabrook offer placements to students and graduates as part of their placement year or as apprentices which provides opportunities across all product sectors that Reabrook manufacture, not just Health & Beauty.

Do you think women have a particular feel for this work as heavy personal care users or buyers?

Not necessarily, but I guess that having first-hand experience of using some of the products would be an advantage. There are plenty of men who have skincare regimes and use these products - we manufacture plenty of male grooming products such as body sprays, shower gels and shaving preps.
It is true that there are a large number of women working in key positions within the retailers, and of course this also offers good career opportunities.

Are you ‘rare’ in a ‘man’s’ world or are there lots of female scientists

I sometimes feel in the minority when I attend conferences and seminars where women seem to be outnumbered by the men. I am encouraged by the number of young women who are coming through from school and University who are showing an interest in the sector.

CROWN Aerosols UK’s New Apprenticeship Scheme

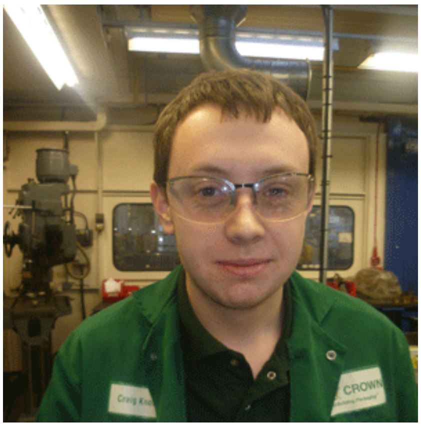
“Re-engineering our Future"

When I first started my apprenticeship there was a lot of new information to a take in because it was a totally different job compared to what I had previously done.

I started off in the tool room where i learnt basic bench fitting techniques and then progressed onto using lathes, millers and other machinery that I would need to use on a daily basis in months to come.

Now starting the third year of my apprenticeship my skills have improved dramatically and my confidence in doing jobs has also grown throughout, this is all thanks to the great training I have received from my training mentor as well as other engineers throughout the company.

Danny Lewis



When I first applied for a job as an apprentice Engineer, I was still unsure about what career path I wanted to take. As I settled into the job, I found myself enjoying the work more and more often. By the end of the first year I was confident in the fact that engineering was where I wanted to be. A big part of this was down to my training co-originator and other engineers who taught me a great deal about production engineering. Through my training I have gained a great deal of confidence in my work which I try to improve on a daily basis.

Three years down the line I can not see myself in any other career. My job is a big part of my life and I am happy that I have chosen to work in an area which will allow me to develop my career.

Craig Knowles

"Myself, I have worked at our Sutton plant for the last 19 years and have seen many apprentices pass through our scheme. Over the last few years I have seen an unsurpassable apprentice scheme develop and grow into what I believe as a World Class apprenticeship scheme. From my previous role working as a Machine Setter operator in our Canline department, I was really happy to have been successful in securing an adult apprenticeship within the company. I am also very honoured to have a skilled and dedicated Mentor such Terry Reeves. I have now near on completed my apprenticeship and I am looking forward to putting my skills and knowledge gained into action."

Anthony Birch

Adult Apprentice

"When I was asked to take on the role as the Apprentice Mentor, I thought this would be a good opportunity to pass on my skills and knowledge that I have gained over the year's tool making and working at Crown.
I completed an A'1 assessors course – This gave me a good insight to all aspects of the NVQ and what is required from it, from both levels 2 and 3.

All apprentices have to achieve this, in order to complete their training. In my opinion, I consider the training scheme at Crown, Sutton-in-Ashfield, is much more like the apprenticeship that I received and I consider this a very helpful for new apprentices."

Terry Reeves

Apprentice mentor

SECTION 10: The Big BAMA Aerosol Quiz

Level 1 (Basic 11-16)

1. In which country was the first aerosol can made?

2, In which year was the first aerosol can made?

3. How many aerosol cans are made per year in the UK?

4. Name two liquified propellants.

5. Where are liquified propellants stored at an aerosol manufacturer?

6. Which of these propellants is an ideal gas?
    PROPANE   BUTANE   NITROGEN   ISO-BUTANE

7. What is the highest safe temperature for an aerosol?

8. What happens inside an aerosol when it is tested in a water bath at 50 ^{o}C ?

9. What are the two metals used to make aerosol cans?

10. What type of welding is used to weld the seam of a steel aerosol can?

11. What process is used to fix the valve assembly into the top of an aerosol can?

12. What is the dry ingredient in dry shampoo?

13. What type of propellants never leave the can?

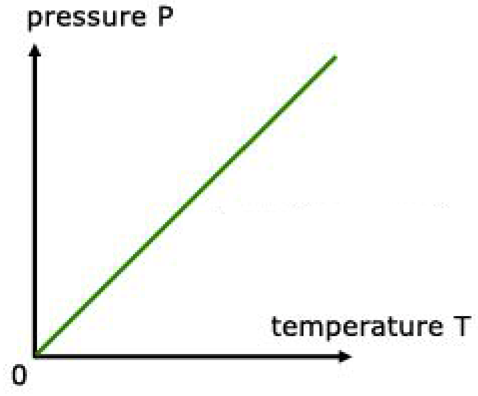
14. What is the smallest safe size for aerosol particles to avoid breathing them into the lungs?

15. What is 50 microns written in standard form and SI units?

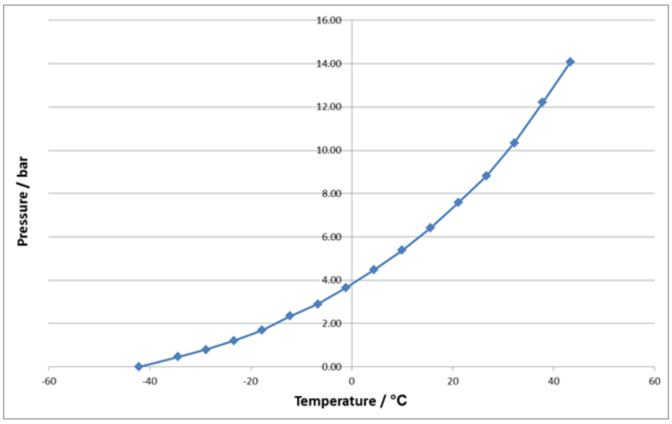
Level 2 (Hard 16+)

1. How is static electricity prevented in rubber conveyor belts?

2. In this graph what must the temperature units be?



3. This is a graph of pressure against temperature for which propellant in an aerosol can?

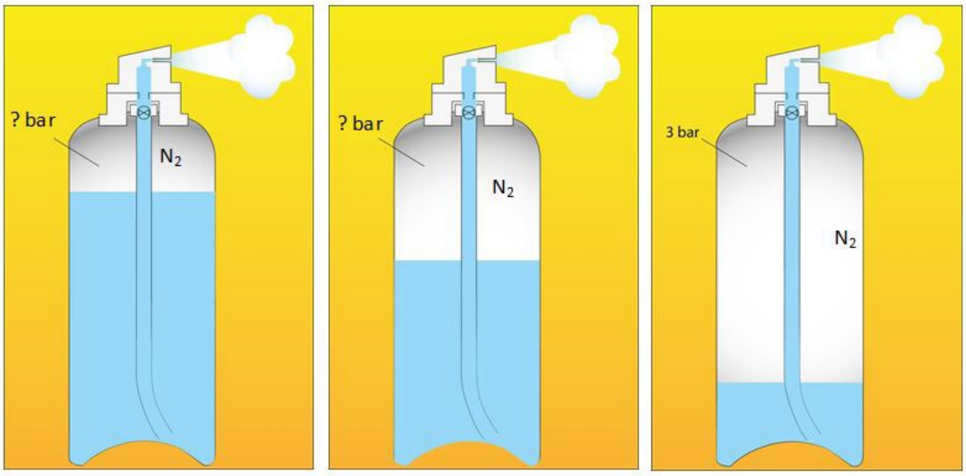


4. The graph in question 3 shows the pressure line reaching zero at -42 ºC. What happens to the propellant vapour at that temperature?

5. Why are storage tanks for liquified propellants painted white

6. This diagram shows 3 cans filled with nitrogen propellant. When the can is almost empty the pressure is 3 bar.

Estimate the pressure for the full and half full can.



7. Which of these are correct descriptions for the nitrogen propellant in the can?
   LIQUIFIED VOLATILE REACTIVE INERT VAPOUR IDEAL

8. Aerosols must not produce spray droplets less than 10 microns diameter. Why not?

9. What type of radiation is absorbed by propane gas?

10. Why are flammable gas sensors placed near the ground in aerosol filling buildings?

ANSWERS

Level 1 (Basic 11-16)

1. In which country was the first aerosol can made?
NORWAY

2, In which year was the first aerosol can made?
1929

3. How many aerosol cans are made per year in the UK?
1.4 BILLION

4. Name two liquified propellants.
PROPANE, BUTANE, ISOBUTANE are all correct

5. Where are liquified propellants stored at an aerosol manufacturer?
IN A TANK FARM WELL AWAY FROM THE MAIN BUILDINGS

6. Which of these propellants is an ideal gas?
   PROPANE BUTANE NITROGEN ISOBUTANE

NITROGEN

7. What is the highest safe temperature for an aerosol?
50 ºC

8. What happens inside an aerosol when it is tested in a water bath at 50 ºC ?
THE PRESSURE RISES

9. What are the two metals are used to make aerosol cans?
STEEL AND ALUMINIUM

10. What type of welding is used to weld the seam of a steel aerosol can?
RESISTIVE WELDING

11. What process is used to fix the valve assembly into the top of an aerosol can?
CRIMPING

12. What is the dry ingredient in dry shampoo?
RICE STARCH

13. What type of propellants never leave the can?
INERT IDEAL GASES

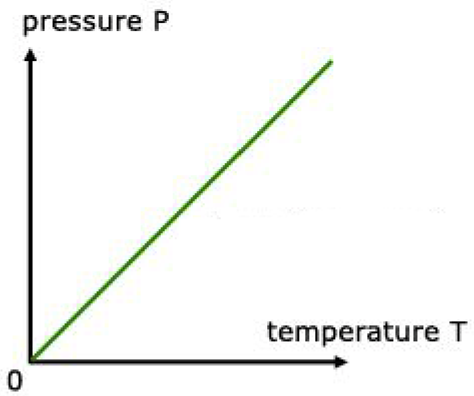
14. What is the smallest safe size for aerosol particles to avoid breathing them into the lungs?
10 MICRONS

15. What is 50 microns written in standard form and SI units?
5×10^{-5} m

Level 2 (Hard 16+)

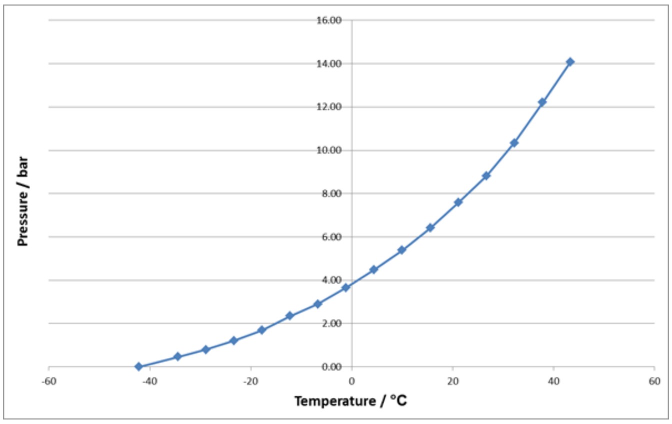
1. How is static electricity prevented in rubber conveyor belts?
CARBON IN THE RUBBER POLYMER TO MAKE IT CONDUCTIVE

2. In this graph what must the temperature units be?



AS THE LINE GOES TO ZERO THE UNITS MUST BE KELVIN

3. This is a graph of pressure against temperature for which propellant in an aerosol can?



THIS LINE IS FOR PROPANE VAPOUR IN THE PRESENCE OF LIQUID PROPANE

4. The graph in question 3 shows the pressure line reaching zero at -42 ºC. What happens to the propellant vapour at that temperature?

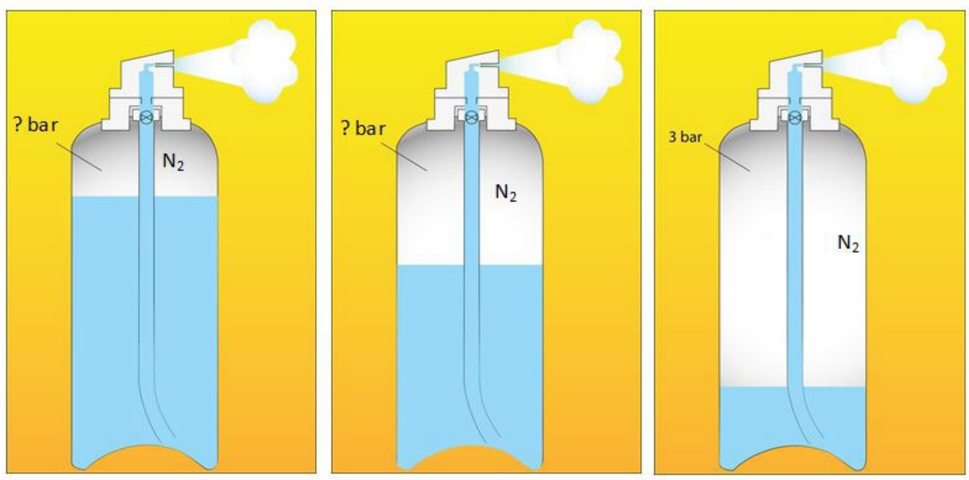
THE VAPOUR CONDENSES INTO THE LIQUID PHASE

5. Why are storage tanks for liquified propellants painted white?

TO PREVENT OVERHEATING IN BRIGHT SUNLIGHT BY REFLECTING MOST OF THE SOLAR RADIATION

6. This diagram shows 3 cans filled with nitrogen propellant. When the can is almost empty the pressure is 3 bar.

Estimate the pressure for the full and half full can.



THE MIDDLE CAN GAS VOLUME IS ABOUT HALF OF THE NEARLY EMPTY CAN SO THE PRESSURE WILL BE ABOUT 6 BAR.
THE FULLEST CAN IS ABOUT HALF THE VOLUME OF THE MIDDLE CAN SO THE PRESSURE WILL BE ABOUT 12 BAR

7. Which of these are correct descriptions for the nitrogen propellant in the can?
   LIQUIFIED VOLATILE REACTIVE INERT VAPOUR IDEAL

NITROGEN IS INERT AND IT IS AN IDEAL GAS (IT OBEYS THE GAS LAWS)

8. Aerosols must not produce spray droplets less than 10 microns diameter. Why not?
PARTICLES SMALLER THAN 10 MICRONS CAN REACH THE ALVEOLI IN THE LUNGS.

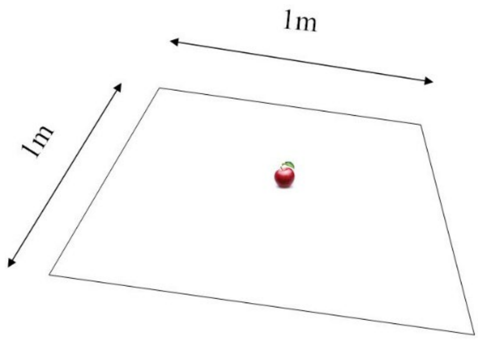
9. What type of radiation is absorbed by propane gas?
INFRARED

10. Why are flammable gas sensors placed near the ground in aerosol filling buildings?
PROPANE AND BUTANE HAVE LARGE ORGANIC MOLECULES AND A HIGHER DENSITY THAN AIR. THESE GASES SINK IN AIR. THEY HAVE NO ODOUR. WHEN GASES ARE USED FOR HEATING AND COOKING A STENCHANT IS ADDED TO MAKE THEM SMELL UNPLEASANT. THIS IS NOT POSSIBLE IN AEROSOLS.

APPENDIX: HELP WITH PRESSURE:

Scientists work in **SI Units**. For pressure this means newtons per square meter (Nm^{-2}). SI units are named

after famous scientists and the pressure unit of 1 Nm^{-2} is named after **Blaise Pascal**, so 1 Nm^{-2} = 1 Pa



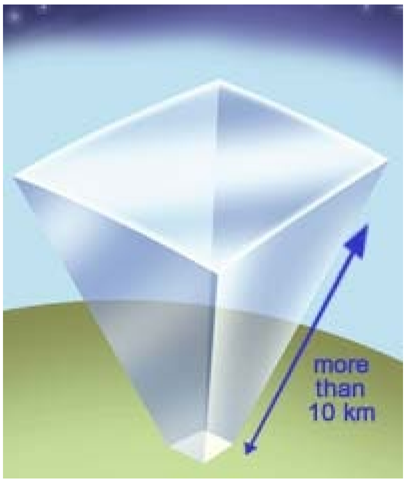
1 Pa is a tiny pressure equivalent to one newton (the weight of a small apple) over one square metre.

To keep life simple, the kilopascal (kPa) is normally used.

1 kPa = 1000 Pa = 1000 Nm^{-2}

By a lucky coincidence 100 kPa is very close to the pressure of the atmosphere at sea level. That pressure is caused by over 10 km of atmosphere sitting on top of us.

100 kPa ≈ 1 atm (1 atmosphere)



Another name for 100 kPa is 1 bar, so

100 kPa = 1 bar ≈ 1 atm

The bar is a useful unit because it relates to normal atmospheric pressure. A tyre with 3 bar is 3 times atmospheric pressure.
In this unit we will use bar for the pressure in an aerosol can.

Download our Aerosols and Pressure poster here

aerosols_and_pressure-poster.pdf

This pressure gauge is calibrated in kPa. Look at the black text.
But what is the red text? This is not an SI unit!
Where was the gauge made? The Americans still use pounds per square inch and so do many other countries. Even in Europe you will still find psi on gauges for cycle and car tyres and most engineering uses.

It gets worse! This gauge is calibrated in kg/cm^2 and psi.

This is a simple honest gauge calibrated in bar, but can we trust it?

Unfortunately....

GAUGES ARE LYING!

When this gauge reads zero, what it means is 1 bar because the atmospheric pressure all around us is 1 bar.

Gauges tell us what the pressure is ABOVE atmospheric pressure. For normal things like tyres we can ignore the extra bar from the atmosphere, but scientists and engineers have to know exactly what the pressure is and not forget the extra bar.

The pressure in this tyre is 1 bar, but so is the pressure outside, so the tyre is flat. A pressure gauge will read zero.