Investigation of a Manufactured Article

Cigarette Lighter

Dr. Rob Wallach

Department of Material Science and Metallurgy
University of Cambridge

This is part of a set of resources on the topic.

- Powerpoint summary
- Supervisor Guide
    - For teaching assistants or instructors giving a background and answers to likely student questions.
- For Students
    - MiniProject - Investigation of a manufactured article
        - Explaining the project
    - Instructions for Dismantling
        - How to do this safely
    - Data Booklet
        - With lab test data for reference
    - Materials Selection for a Lighter
        - Instructions on materials selection methodology and how to use CES EduPack.

Answers/comments for demonstrators: 1A mini-project

How does the lighter work?

Students have the opportunity to examine a working lighter and to dismantle an empty lighter, and have access to an exploded diagram showing all the parts. In addition, two photographs of cross-sectional views through the lighter are available. One shows the whole lighter, and the second shows just the electronic assembly, containing the piezo ceramic and the mechanism for imparting a force on it.

Two conditions are necessary for the lighter to ignite: the fuel must be allowed out of the tank, and a spark must be created to cause ignition. Both of these are achieved by pushing the button. Gas is allowed to escape for as long as the push button is held down. When the push button is released, the fuel is cut off, extinguishing the flame.

1) Mechanical operation

Pushing the button causes the conductor to press down on one end of the lever. The lever pivots on a moulding on the interior of the bracket and is held in place by the pole base. The other end of the lever locates within a ring on the nozzle, so the nozzle is pulled upwards when the button is pressed. The upper coil assembly functions as a valve, which opens when the nozzle is pulled upwards.

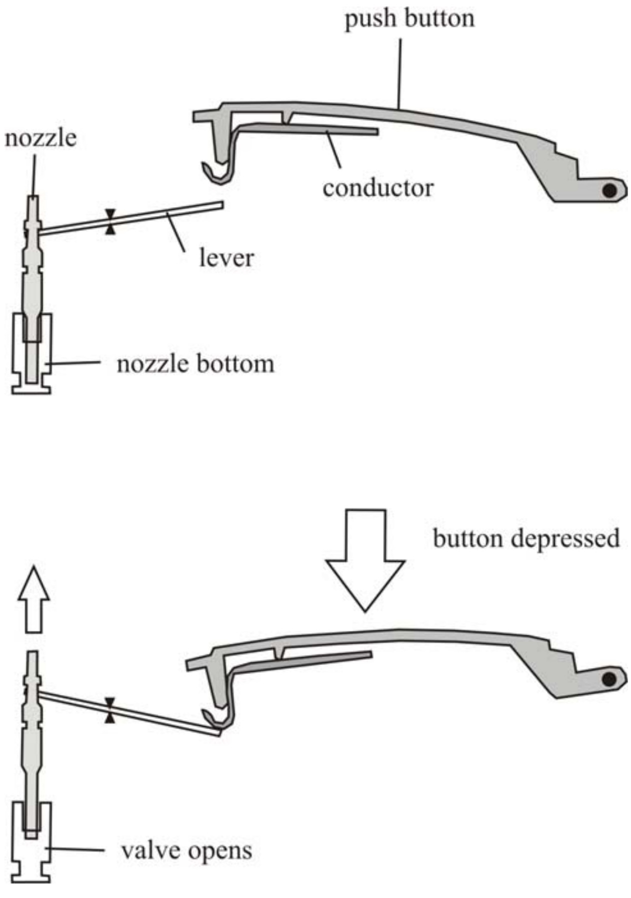


Figure 1. Opening of upper coil (nozzle) valve when push button is depressed.

When the valve opens, butane gas evaporates from the liquid and escapes from the tank *via* the nozzle. It passes through the sponge, wick and filter paper – all of these act to filter the fuel but their principle role is to provide a large surface area from which the liquid butane can evaporate. The butane vapour mixes with air as it comes out of the nozzle – the punched slots in the cap allow air to enter the lighter body, and springs A and B allow air to enter the gas stream.

The flame height is controlled by the adjusting ring – this unscrews or tightens the upper coil to allow the valve to open more or less.

A filling valve on the bottom of the lighter allows butane from a high-pressure aerosol canister to be added to the tank. This is a non-return valve that is normally held closed by the valve spring. This valve is difficult to remove and cannot easily be examined. A schematic diagram of a similar valve is available in the demonstrator's information.

2) Electrical operation

As the button is pressed, the electronic assembly is compressed. This compression is taken up by the action spring (which is noticeably stiffer than the reset spring), since the hammer is held in place by the hammer pin. The hammer pin passes through two shaped slots in the inner case, and each end locates in an 'L' shaped groove on the inside of the outer case. As the assembly is compressed, the inner case slides along the hammer, causing the hammer pin to rotate. Eventually the ends of the hammer pin reach the 'leg' of the L shaped slot, at which point the hammer is released. The action spring propels the hammer into the head metal, so that the piezo unit is compressed between the head metal and the backmass. The inertia of the backmass ensures that the maximum stress is rapidly imparted to the piezo unit. When the button is released, the reset spring returns all the components in the electronic assembly to their original positions.

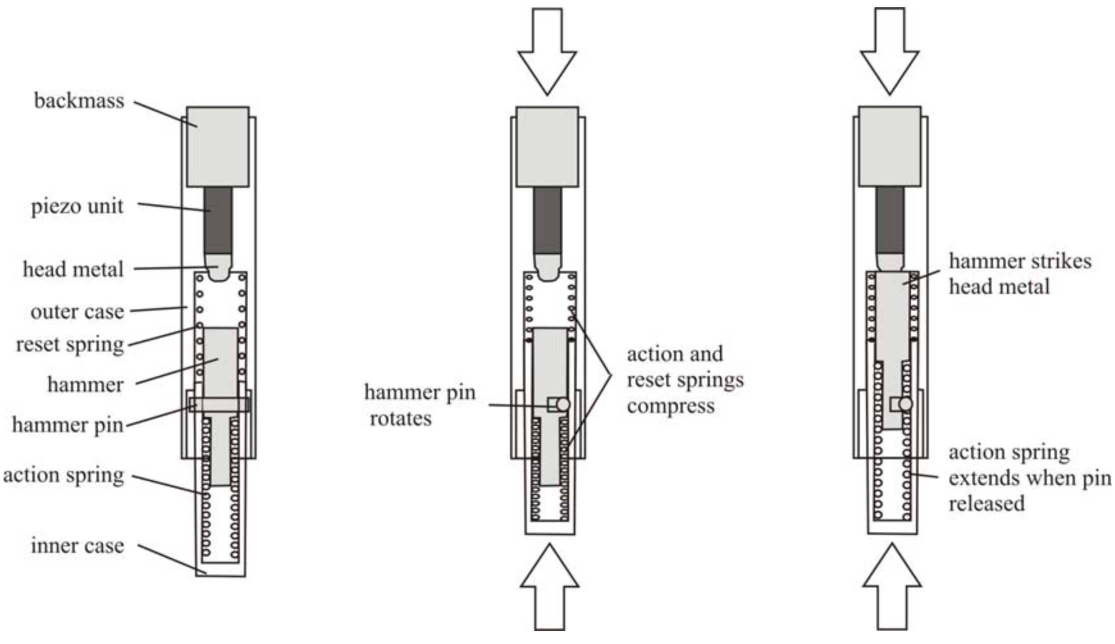


Figure 2. Compression of electronic assembly leading to release of hammer.

The potential difference that arises across the piezo ceramic is transferred to the area of the nozzle by an electrical path that is not intuitively obvious. One electrode is the spring at the tip of the nozzle. Charge is transferred to this electrode through the backmass, the conductor in the push button, and finally the lever. This path is only complete when the push button is depressed. The other electrode is the tip of the pole leader, held in place by the pole base. The charge is transferred to the other end of the pole leader from the piezo ceramic *via* the head metal, the hammer, the action spring and the electronic assembly stand (made from a carbon-filled polyamide).

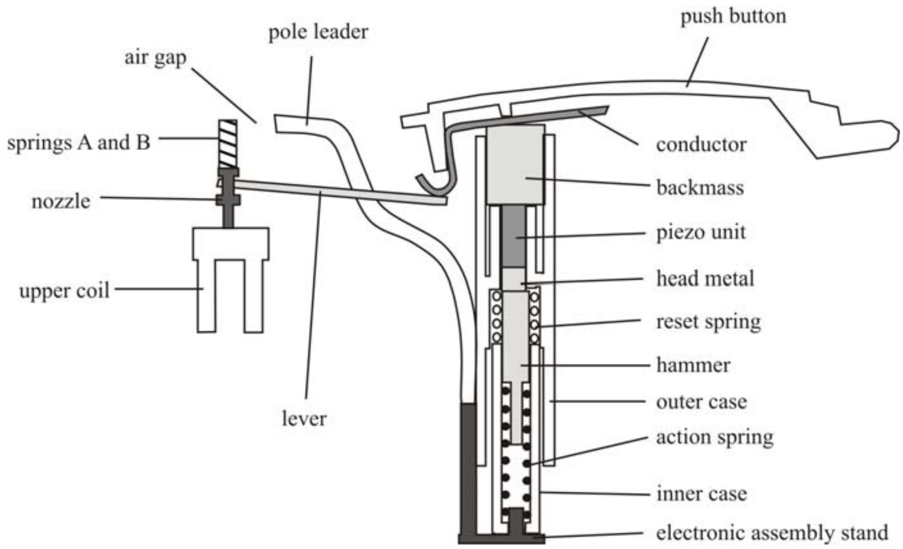


Figure 3. Components involved in conducting charge from the piezo unit to the air gap when push button is depressed.

3) Stress required to cause a spark

Students should include an estimate of the stress required to produce a spark across the gap between the electrodes in their report. The dimensions of the piezo unit and the size of the air gap must be measured during inspection and dismantling of the lighter. The concepts were covered in Course B.

The stress σ required to produce voltage V across a piezoelectric ceramic with relative dielectric constant κ, piezoelectric coefficient d_0, and thickness L is

$$\sigma = \frac{\varepsilon_0 \kappa V}{d_0 L}$$

where ε_0 is the permittivity of free space. The air gap is 2.8 mm when the button is depressed, and the minimum voltage required to produce a spark over this gap is 2800 V, taking the breakdown field strength of air as 1 MV m^{-1}. If it is assumed that there are no resistive losses in the electrical circuit, then V = 2800 V in the above equation (in practice, there will be resistive losses throughout the circuit). The ceramic is PZT, with L = 5 mm. From the Data Book, $d_0 = 171 \times 10^{-12}$ C N^{-1}. (note that d varies appreciably, see http://www.efunda.com /materials/piezo/material_data/matdata_output.cfm?Material_ID=PZT-4).

Commercially available PZT grades have κ ranging from 1000 to 3000, so taking κ = 2000, one finds:

$$\sigma = \frac{\varepsilon_0 \kappa V}{d_0 L} = \frac{8.854 \times 10^{-12}.2000.2800}{171 \times 10^{-12}.5 \times 10^{-3}} \approx 58\,\text{MPa}$$

Since the ceramic has a diameter of approximately 3 mm, this corresponds to a force of 410 N acting on the ceramic. This is a conservative estimate for the force supplied by the mechanical system since the efficiency of the piezoelectric ceramic will be less than unity.

General comments about manufacturing of the lighter

The most important consideration in goods of this type is cost of manufacture. While the sales price of this lighter (60 p wholesale, 15 p ‘factory door’) is very low, it is actually one of the more expensive models of plastic lighter on the UK market. This lighter meets the required standards (ISO 9994) for sale in the United States and incorporates more strengthening and safety features than the cheaper models, some of which are produced at a unit cost of less than 2 p.

The vast majority of the polymeric components in the lighter are made by injection moulding. Despite the initially high cost of tooling, injection moulding offers very low unit cost and sufficient speed for large production runs. Dimensional tolerance is good in injection moulded goods, and this is important here to prevent leakage of lighter fluid.

The lighter is designed in the style of a traditional metal Ronson lighter, where the filling hole used to be on the back edge, opposite the cap. This feature is repeated in the plastic lighter, where the ribbed pattern provides extra stiffening to the tank.

Components to be studied

Piezo unit

Function: Provide voltage for ignition spark

Material: The EDS and XRD data in combination suggest PZT (lead zirconium titanate). This is a well-known piezoelectric material, capable of producing a large voltage in a small and light unit. The XRD data are consistent with a rhombohedral crystal structure (see lists of reference *d*-spacings), but the exact position of the compound on the phase diagram cannot be determined from the data as presented. The composition could be determined by calculating accurate values of the lattice parameters from the XRD data (with knowledge of the wavelength of X-rays used), or quantitative EDS data could be used. The material is unlikely to be pure (a reflection of the low cost) – in fact, some calcium is present according to the EDS data.

Manufacture: Sintered PZT powder, poled on cooling to give maximum *d* along the compressive axis. Dimensional tolerance is not critical (the piezo unit is glued into place) so no further processing will be required.

Nozzle bottom

Function: Forms part of the valve mechanism in the upper coil assembly

Material: Brass (microstructure suggests two-phase). EDS spectrum shows copper and zinc, as expected, plus some lead. The lead is also visible in a backscattered SEM image (not given to students). The lead improves the machinability of the brass. Brass is corrosion resistant and easily machined, and relatively cheap.

Manufacture: Probably machined from rod stock – gives good dimensional tolerance required for valve function.

Hammer

Function: Imparts force to head metal and hence to piezo unit.

Material: SK-5 medium carbon ‘tool’ steel. A hard steel is required since plastic deformation of the hammer would reduce the energy available to be transmitted to the piezo unit. The EDS spectrum shows some manganese (carbide former). The microstructure is fine, and shows lots of carbide. These factors increase the resistance to plastic deformation.

Manufacture: Machined from rod stock

Back mass

Function: Provides inertial mass for piezo unit to be forced against when hammer strikes.
Material: Zinc casting alloy, containing some Al (EDS). Dendritic microstructure on fine scale. Often shows considerable porosity.
Manufacture: Die cast. The porosity is a reflection of the cost – a cheap alloy will be used, and the casting conditions will not be carefully controlled. The choice of this material and manufacturing method reflects that dimensional tolerance and mechanical performance are not as important as mass and cost.

Cap [students not asked to analyse or report on this component]

Function: Acts as a wind shield for the flame and a finger guard for the moving components and electrical spark in the nozzle area. The slots in the cap allow air to reach the nozzle. The cap also has a decorative role: the Ronson logo is stamped into the side.
Material: Nickel-plated mild steel. The selective EDS data shows the nickel coating and the ferrous interior. The microstructure of the interior is typical of a (cheap) mild steel. The nickel coating gives some corrosion resistance and a glossy metallic appearance.
Manufacture: The part is probably punched from a flat sheet, using a die that cuts the overall shape of the part and the air holes, and punches the Ronson logo in one step. The part would then be bent around a former and electroplated with nickel.

Upper Coil [students not asked to analyse or report on this component]

Function: Supports the nozzle and seals the gas in the tank; forms a part of the valve mechanism in the upper coil assembly.
Material: Poly(oxymethylene) – POM. A relatively cheap, fire-resistant polymer used for many of the parts in the lighter.
Manufacture: Most likely to be injection moulded, although the thread may have been machined to give the required tolerance (although this is a more expensive option).

Tank [students not asked to analyse or report on this component]

Note that this component has been used in both the video and the CES additional notes to illustrate the use of the CES software which they should be encourage to consult for additional selection and fabrication information.

Function: Contains the liquid butane lighter fuel. Internal ribs add strengthening.
Material: Acrylonitrile-styrene copolymer (AS or SAN). Stiff polymer with good resistance to organic solvents. [Note that the IR spectra for the AS tank and the ABS bracket are almost identical, except that C=C absorbances are seen at ~970 and ~1650 cm^{-1} in the ABS spectrum due to the presence of butadiene that are absent in the AS spectrum.]
Manufacture: Injection moulded.

Bracket

Function: Contains key components of the lighter. Has a rough texture to improve grip on the lighter, also helps cosmetically (compare the textured exterior to the glossy interior).
Material: Acrylonitrile-butadiene-styrene (ABS). Not as stiff as AS, but cheap and impact-resistant (used extensively in the automotive industry).
Manufacture: Injection moulded.

Pole base

Function: Holds electrode end of pole leader in place, holds lever in place, lobes on front edge act as a windshield for the nozzle, and prevent spark from arcing to cap rather than nozzle.
Material: Nylon (probably filled with carbon black), with high melting point and service temperature.
Manufacture: Injection moulded.

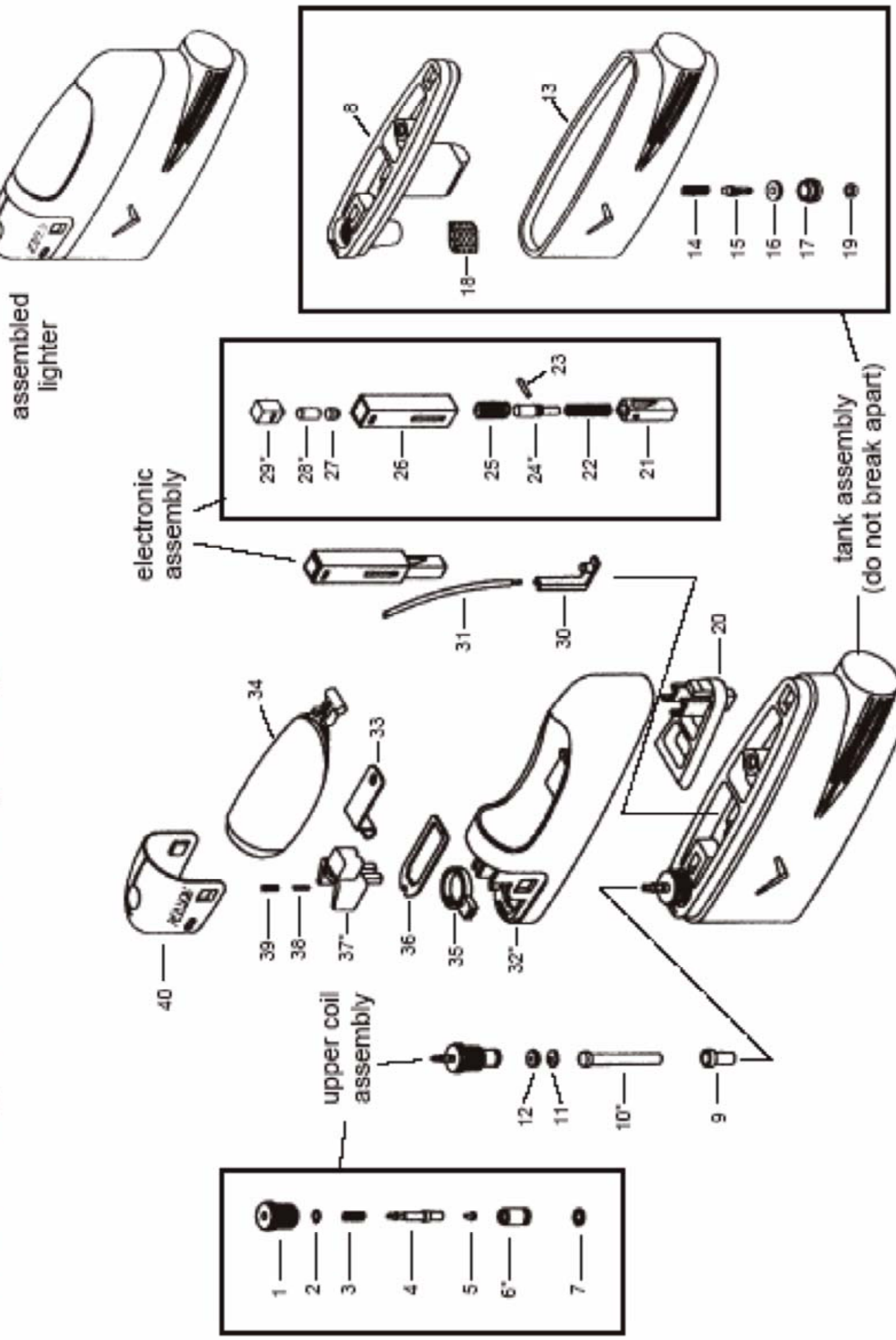
Wick

Function: Filters lighter fluid and allows fluid to rise to nozzle by capillary action.
Material: Poly(ethene) (PE). The material specified by the manufacturer is PVC, but has clearly been substituted in this case – almost certainly for reasons of cost or availability. The SEM picture shows that this is a PE foam with open porosity to allow the butane to pass through and evaporate from the large surface area.
Manufacture: The porous structure of the wick is quite unusual – it does not appear to be a 'standard' polymer foam or a partially sintered polymer powder. One possibility is that this is a 'macroporous' polymer, formed from polymerising a monomer in the presence of a porogen that is soluble in the monomer but not in the polymer. After polymerisation, the porogen is washed out. The wicks could be made individually in moulds using this method, but this would perhaps be too expensive.

Component Number	Component Name	Function	Material (according to manufacturer)
1	upper coil	see text	
2	small o-ring	part of upper coil valve	nitrile-butadiene rubber (NBR)
3	nozzle spring	closes upper coil valve	stainless steel
4	nozzle	allows gas out of tank	brass
5	T-packing	seals upper coil valve when closed	NBR
6*	nozzle bottom	see text	
7	large o-ring	part of upper coil valve	NBR
8	cover	see text	
9	wick holder	holds wick	zinc die casting alloy
10*	wick	see text	
11	T-disk	part of upper coil valve	zinc alloy
12	filter paper	filters gas	leather and sponge
13	tank	see text	
14	valve spring	closes filling valve	stainless steel
15	valve	filling valve	poly(oxymethylene) (POM)
16	valve large ring	seals filling valve	NBR
17	bottom cover	secures filling valve	acrylonitrile-styrene copolymer (AS)
18	sponge	filters and allows evaporation of fuel	sponge
19	valve small ring	part of filling valve	NBR
20	support stand	holds push button in place	acrylonitrile-butadiene-styrene (ABS)
21	inner case	part of electronic assembly, rotates hammer pin	POM
22	action spring	Fires hammer at piezo	spring steel
23	hammer pin	holds hammer back until fired	mild steel
24*	hammer	see text	
25	reset spring	returns hammer to original position after firing	steel
26	outer case	houses piezo unit	POM
27	head metal	transmits hammer blow to piezo unit	tool steel
28*	piezo unit	see text	
29*	backmass	see text	

Component Number	Component Name	Function	Material (according to manufacturer)
30	electronic assembly stand	supports electronic assembly, conducts charge to pole leader	Carbon-filled polyamide (EB-10)
31	pole leader	forms electrode at nozzle	copper with poly(vinyl chloride) insulation
32*	bracket	see text	
33	conductor	transfers charge to lever	brass
34	push button	operates lighter	ABS with metal coating
35	adjusting ring	controls flame height	ABS
36	lever	operates upper coil valve	steel
37*	pole base	see text	
38	spring A	forms electrode at nozzle	stainless steel
39	spring B	forms electrode at nozzle	stainless steel
40	cap	see text	

Ronson Lighter Assembly Diagram



No.	Description	Material	Data, etc. provided*	Material	Manufacture
28	piezo unit	ceramIC	X -ray diffraction trace, EDS data	PZT	Sintered powder, poled
6	nozzle bottom	metallic	metallographic sample (red mount), EDS data	Brass (alpha-beta)	Machined from rod
24	hammer	metallic	metallographic sample (green mount), EDS data	SK-5 'tool' steel	Machined from rod
29	back mass	metallic	metallographic sample (black mount), EDS data	Zinc casting alloy (some Al addition)	Die Cast
33	conductor	metallic	metallographic sample (black mount), EDS data	Cu-5%Sn-1 %Zn	
1	upper coil	polymeric	IR spectrum, property data	Polyoxymethylene (POM)	Either IM then threads machined, or machined from stock
10	wick	polymeric	IR spectrum, SEM pictures, property data	PE foam	Probably “macroporous” route
13	tank	polymeric	IR spectrum, property data	Acrylonitrile-styrene copolymer (AS or SAN)	IM
32	bracket	polymeric	IR spectrum, property data	ABS	IM
37	pole base	polymeric	IR spectrum, property data	Nylon 6,6	IM

Author

We would like to thank Dr. Rob Wallach of the Materials Science and Metallurgy Department of the University of Cambridge for contributing this resource. You can contact him via the website www.msm.cam.ac.uk.

Reproduction

These resources have been contributed on the basis that you can download and reproduce these resources in order to use them with students. You should make sure that the author and their institution are credited on any reproductions.

You cannot use this resource for any commercial purpose.

Accuracy

We try hard to make sure that resources in Granta's Teaching Resource Website are of a high quality. If you have any suggestions for improvements, you can contact the author using the contact details above.

Other resources include:

19 PowerPoint lecture units

Exercises with worked solutions

Recorded webinars

Posters

White Papers

Solution Manuals

Interactive Case Studies

GRANTA
TEACHING RESOURCES