

**Granta EduPack MicroProjects**

**Materials Science and Engineering**

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**EDUCATION RESOURCES**

These ***MicroProjects*** are short investigations that can be completed in less than an hour. Each poses a set of questions that can be answered using the Granta EduPack Material Science and Engineering (MS&E) database. The database needed for each project will be highlighted at the top. All start at a level that is readily accessible, using the SEARCH function to find records, creating charts using the CHART/SELECT function, and extracting relevant data from a Record and its linked SCIENCE NOTES. Hints in gray help with any difficult step.

Each MicroProject has an attached Discussion Point – a challenge to go further – highlighted in red and separated from the MicroProject by this separator:



The Discussion Point poses a question linked to or arising from the MicroProject. Responding to the Discussion point requires independent thought and research, takes longer, but is rewarding if followed. It is an add-on for more advanced study.

Each MicroProject and its Discussion point has a fully worked Sample Response, available to the instructor. The charts shown in the responses are reproduced here exactly as produced by Granta EduPack.

Example Use: In-class activities, homework assignments, activity to introduce students to functionalities of Granta EduPack

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# Zirconia, a ceramic that thinks it’s a metal

Database: MS&E

* What is Zirconia? (Use the Search facility to find the record. To copy and reuse text and images from a record: right click on the opened record, select Copy,

then open WORD and Paste. The entire record is pasted into WORD. You can then copy and re-paste the bits you want for a report.)

* What makes it special among ceramics? (Explore the record to find out.)
* What is the value of its Fracture toughness?
* How does this compare with the Fracture toughness of other ceramics? Make a bar-chart of Fracture toughness for Technical ceramics to find out. (When you open the “Materials” data-table of the MS&E DB, a set of panels, each labeled with a sub-set of materials, appears on the right. One panel says “Technical Ceramics”. Clicking on that limits the selection and charts to technical ceramics.)
* Reset the scale from log to linear and adjust its range to run from 0 to 10. (To make the changes, double click on the axis name to re-open the Axis Settings box, select “Linear” and adjust the range.)
* What does “Fracture toughness” measure? (Try the information (“i”) link next to the property name on any materials record to access Science notes.)



## Discussion Point

What gives Zirconia its unusual Fracture toughness?

# Are biopolymers really greener than oil-based plastics?

Database: MS&E

* What is PLA? (Use the Search facility to find the record for PLA. You can copy text and images from the record. To do so, open the record, right-click and copy

– the entire record is copied – then paste into WORD – the whole record appears. Select and copy the bits you want to paste into a report.)

* What is PLA made from if it isn’t oil? (Explore the record to find out.)
* What is PLA used for? (Explore the record to find out.)
* Are there other commercial biopolymers? (Use the Search facility to find records containing the word Biopolymer.)
* Are all biopolymers bio-degradable? (Open a Limit stage, go to “Material recycling: energy, CO2 and Recycle fraction” (right at the bottom of the list) and click on Biodegrade. Add a Tree stage to limit the selection to Polymers and Elastomers. Which biopolymers pass?)
* Are the CO2 footprints for primary production of biopolymers less than that of polystyrene, with which they compete for packaging? To find out, make a bar-chart of “CO2 footprint, primary production” with biopolymers and polystyrene on it. Use a linear scale for CO2 footprint. (You can limit the bar chart to the materials you want to study by clicking on Chart/Select – Select from: “Custom – Define your own subset”, then selecting the materials you want on the chart. To change to a linear scale: double click on the axis label to expose the Axis Settings, and select Linear.)
* Are biopolymers cheaper than polystyrene? Make a bar chart of Price per kg for the same subset of materials. Use a linear scale for Price.



## Discussion Point

The projected production of PLA is expected to rise to 1 million tonnes per year by 2020. If 7.5 m2 of fertile land are needed to provide feedstock for 1 kg of PLA, what area (in km2) will be required to support the 2020 production? How does that compare with the area of country or State in which you live?

# Nichrome - the glowing heart of dryers and toasters

Database: MS&E

* What is Nichrome? What is its composition? What, typically, is it used for? (Use

the Search facility to find the record. To copy text or images from the record,

open it, right-click and copy – the entire record is copied – paste into WORD, then select and copy what you want to paste into a report)

* What is its Maximum Service Temperature range?
* What does “Maximum service temperature” measure? (Try the information (“i”) link next to the property name on any materials record to access Science notes.)
* How does the Maximum service temperature of Nichrome compare with that of other metals? Make a bar-chart of this property, limiting it to metals. (When you open the “Materials” data-table of the on the Home page and click on Chart/Select you are prompted to Select a subset. Choose “Custom: Define your own subset”, then use the panel that appears to select just “Metals and Alloys”).
* Compare the prices of the three metals with the highest maximum service temperatures. (Price per kg appears in the record for each material. To choose the currency, go to Settings – Units – Preferred currency.)



## Discussion Point

Which alloying elements impart high temperature oxidation resistance? How do they do it?

# Is spider silk really stronger than steel?

Database: MS&E

* Spider silk is a natural fiber. Spiders webs use strong, relatively stiff silk for the radial “drag-line” strands and a more compliant, resilient “viscid” silk for the

circumferential strands. It is sometimes claimed that spider drag-line silk is stronger than steel. To get an overview of the strength and modulus of natural and man-made fibers, make a chart with Tensile strength on the y-axis and Young’s Modulus E on the x-axis. (Use a Tree stage to isolate “Natural fibers” and “Man-made fibers”, removing all other materials from the chart. Create the chart and add envelopes for Natural and Man-made fibers by clicking on Show family envelopes in the tool-bar across the top of the chart.)

* Label the materials on the chart. “Patented” steel wire (Piano wire) and Spider drag-line silk appear on it. Recolor the steel red to distinguish it from all the others. Is drag-line silk stronger than steel? Is it stiffer, meaning a higher Young’s modulus? (To recolor: Right click on the record name on the chart and select “Record Color”.)
* Is it possible that the more accurate statement is that spider silk is stronger than steel per unit weight σts/ρ(“Specific strength”) where ρ is the density? Make a new chart with σts/ρ on the y-axis and E/ρ on the x-axis. Does drag-line silk have higher specific strength than steel piano wire? (Use the Advanced option in the Axis choice window to create the functions of properties.)
* Which fiber has the highest specific strength? What is it used for?



## Discussion Point

Parachutes are made of strong, light fibers. Long ago they were made of cotton, then silk-worm silk, then nylon, then Terylene, now Kevlar\* or even Zylon, a polyoxazole.

Color all the parachute materials purple in your specific strength plot. What commentary can you make about their evolution over time?

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# What’s special about egg shell?

Database: MS&E

* What is the shell of an egg made of? (Use the Search facility to find the record. You can copy text and images from the record. To do so, open the record, right-

click and copy – the entire record is copied – then paste into WORD – the whole record appears. Select and copy the bits you want to paste into a report.)

* What is the fracture toughness of egg shell? What is its Young’s modulus? (Open the Materials data- table and locate the Biological Materials folder. You will find “Egg shell” in the folder for “Tissue, Mineralized”.)
* How does the fracture toughness of egg shell compare with that of other mineralized tissues? Make a bar-chart of fracture toughness for mineralized tissues and to find out. (Use a Tree stage to isolate “Tissue, Mineralized” in the Biological Materials folder, removing all other materials from the chart. Convert the default logarithmic scale for Fracture toughness to a linear one by double clicking on the axis name and selecting “Linear”.)
* Make the same comparison for Young’s Modulus.
* Why might fracture toughness and modulus be relevant property for the shell of an egg?



## Discussion Point

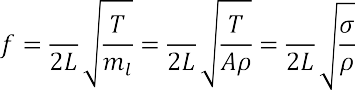
Measuring the mechanical properties of thin, curved shells is not easy. How has the fracture toughness of eggshell been measured? What was the experimental set up? How do you apply controlled loads to the shell without destroying it?

# Materials for acoustic guitars

Database: MS&E

There are two types of acoustic guitars: the classical guitar and the folk guitar. Both have wooden bodies. The classical guitar has nylon strings, but the folk guitar is different – it has metal strings.

* Which wood for the body? SEARCH on “Guitar” to find out. Why does the same wood appear twice in the search results?
* The modulus and the mechanical loss coefficient are key property for the bodies of musical instruments. Modulus affects natural vibration frequencies, and thus resonance and harmonics. Mechanical loss coefficient measures acoustic damping: too little damping and the tone is tinny, too much and it is dull. Make bar-charts for these two properties for Softwoods. What does do they suggest about the guitar-wood? (To limit the Soft woods, click on Chart/Select – Select from: (choose Custom Define your own subset) – deselect all, then select Biological materials - Woods – Softwoods)
* Which metal for strings? Try a search on guitar string or piano string. What is the material that the search brings up?
* The pitch (first harmonic) *f* of a string with a length *l* and mass per unit length *ml=A*ρ carrying a



tension *T* is:

Here *A* is the cross-section area, *ρ* is the density, and *σ=T/A* is the stress in the string. The maximum stress a string support is limited to its tensile strength *σts*. The strings on a guitar are all about the same length, so highest pitch that a string can reach scales as .



Make a bar chart of this quantity with three materials on it: nylon (PA), high carbon steel and Piano wire. Which allows the highest frequencies? ( https://en.wikipedia.org/wiki/String\_vibration)

* The three strings of a classical guitar with the lowest frequencies are made of nylon, but are wound with a metal. Why?



## Discussion Point

What is the history of piano wire? Why does it need to have such a high strength? (https://en.wikipedia.org/wiki/Piano\_wire is informative.)

# Shields for Viking invaders

Database: MS&E

Imagine yourself to be a 12th century Viking seeking a light, tough materials to make shields to protect yourself while you pillage and plunder. The only materials available to you are those that occur naturally, derived from plants or animals.

* “Light” means low density, *ρ*. What does “Tough” mean? (Fracture toughness, *K1c*, and Toughness, *G1c*, differ. The first is in the database, the second is not but can be circulated from the properties that are.)
* How is the property “Toughness” defined in term of the properties that are in the database? (The

science note (i) for Fracture Toughness may help here.)

* Make a bar chart of the Toughness of natural materials. Which three have the highest toughness? (First apply a Tree stage to limit the selection to Biological materials – woods, soft and hard tissue. Then use the Advanced option in the axis-choice panel to create *G1c*)
* That deals with toughness, but what about lightness? Add Density *ρ* to the x-axis. Apply a selection line with a slope of 1 describing light, tough materials (*G1c/ρ*) and move it upwards to find the two best natural materials for shields. What are they?



## Discussion Point

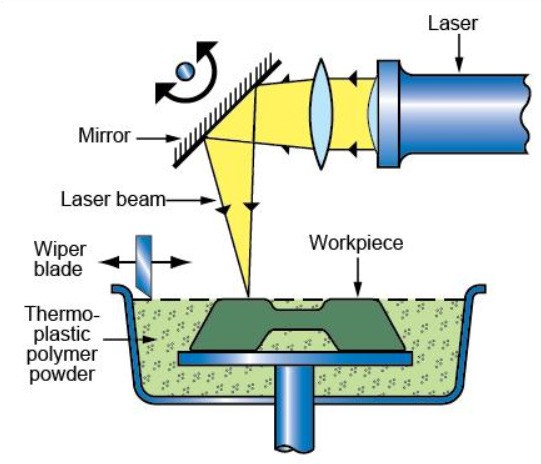
Which of the materials that you have identified really been used for shields in the past? Use the Internet to research materials for shields. What do you find?

# Are materials made by additive manufacture any good? (1-polymers)

Database: MS&E

Selective laser sintering (polymers)

Additive Manufacture (AM) or 3D printing is seen as part of the ongoing “4th Industrial Revolution” (following the

revolutions of steam, electricity and information technology). AM technologies use computer-controlled deposition to build shapes layer-by-layer. All can create shapes of great complexity without the need for dies or molds. But is the material made in this way as good as that made by conventional methods such as injection molding?

* Which polymers can be shaped by AM? (Open the record for the process shown in the figure and copy the materials to which it is linked from the tab at the bottom of the record.)
* Explore the properties of conventional Acrylonitrile butadiene styrene (ABS), for which there is a record in the MS&E DB, by making a chart with Tensile Strength (MPa) on the y-axis and Elongation (%) on the x-axis. (Use the “Define your own subset” option or use a Tree stage to isolate ABS. Just one big bubble appears on the chart.)
* ABS samples made using four different AM machines give the data listed in the table

|  |  |  |
| --- | --- | --- |
| **AM method** | **Tensile strength (MPa)** | **Elongation (%)** |
| PLATCure ABS | 50 - 54 | 4 - 8 |
| ABfled ABS | 26 - 30 | 12 - 15 |
| Accura ABS | 40 - 44 | 10 - 14 |
| DWS Systems ABS | 34 - 37 | 7 - 10 |

Add these materials to the MS&E database. (Adding a new record: Right-click on a chart. Select “Add record”. Enter a name: PLATCure ABS. Enter the data. Return to the chart – PLATCure ABS now appears on it).

* Add a title to the chart, reset both axes from log to linear to give a fair comparison and adjust the range of both to give a well-proportioned chart. How do the properties of ABS made by AM compare to those of conventionally molded ABS? (To adjust an axis, double click on the axis name, then make the changes in the Axis settings box.)

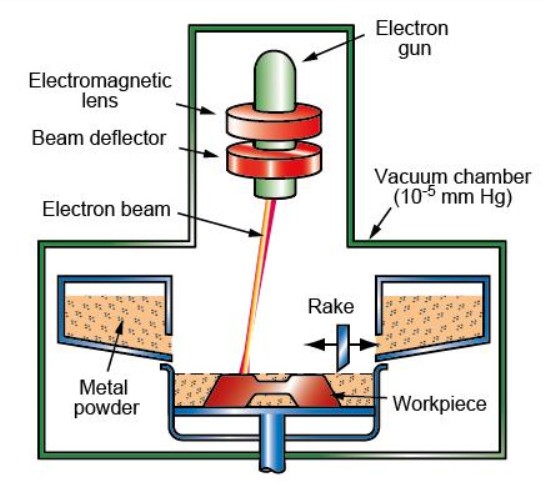


## Discussion Point

The precision and surface quality of AM products are limited, and the process is slow (typically 1 to 20 hours per part). The range of materials that are compatible with AM methods is limited and – as the project showed, the properties may not be as good as those of conventionally processed materials. Who would want to use it? What’s the business case for AM?

# Are materials made by additive manufacture any good? (2-metals)

Database: MS&E

electron beam melting

Additive Manufacture (AM) technologies use computer- controlled deposition to build shapes layer-by-layer. All can

create shapes of great complexity without the need for dies or molds. The precision and surface roughness, at present, are limited to ±0.1mm at best and the process is slow (typically 1 to 20 hours per part) but the freedom of choice of shape is enormous. What about the properties of metals shaped in this way: are they as good as those of materials made by conventional methods such as casting or forging?

* Which metals can be shaped by AM? (Open the record for the process shown in the figure and copy the materials to which it is linked from the tab at the bottom of the record.)
* Explore the properties of conventional Titanium alloys, for which there is a record in the MS&E DB, by making a chart with Tensile Strength (MPa) on the y-axis and Elongation (%) on the x-axis. (Use the “Define your own subset” option or use a Tree stage to isolate Titanium alloys. Just one big bubble appears on the chart.)
* AM methods are new – there are not yet many measurements of the properties of AM materials. The alloy Ti-6Al-4V is one of the most studied. The table lists data from five independent tests.

|  |  |  |
| --- | --- | --- |
| **AM method** | **Tensile strength (MPa)** | **Elongation (%)** |
| Renishaw Ti-6-4 (annealed 750 C) | 1120 - 1150 | 6 – 8.5 |
| Renishaw Ti-6-4 (annealed 850 C) | 1030 - 1070 | 6.5 - 10 |
| SLM Solutions Ti-6-4 (annealed) | 965 - 985 | 9 – 10.5 |
| Optomec Ti-6-4 (no post processing) | 1060 - 1080 | 10 - 12 |
| ARCAM Ti-6-4 (hot-isostatic pressed) | 960 - 985 | 13.5 - 16 |

Add these materials to the MS&E database. (Adding a new record: Right-click on a chart. Select “Add record”. Enter a name: Renishaw Ti-6-4. Enter the data. Return to the chart – Renishaw Ti-6-4 now appears on it).

* Add a title to the chart, reset both axes from log to linear to give a fair comparison and adjust the range of both to give a well-proportioned chart. How do the properties of Ti-6Al-4V made by AM compare to those of conventionally cast Ti-6-4? (To adjust an axis, double click on the axis name, then make the changes in the Axis settings box.)



## Discussion Point

AM is seen as a component of the evolving “4th Industrial Revolution” (following the revolutions of steam, electricity and information technology). The spectrum of materials that can be shaped successfully by additive manufacture is increasing rapidly. Carry out a survey of reports on materials for additive manufacture, linking them to the industrial sector to which they contribute.

# Why don’t things stick to Teflon?

Database: MS&E

* What is Teflon? (Use the Search facility to find the record.)
* What makes it special among polymers?
* Limit the selection that follows to Polymers only. (To limit the selection to Polymers. To do this, click on Chart/Select, then Select from: Custom – Define your own subset. Clear the Subset, then choose Polymers.)
* What is its Maximum Service Temperature of Teflon? How does this compare with the values for other polymers? Make a bar chart of Maximum Service Temperature to find out.
* Use a linear, not a logarithmic, scale and set the ranges to start from zero. (To adjust axes, double click on the axis name to re-open the Axis Settings box, select “Linear” and adjust the range.)
* What is the Dielectric constant of Teflon? How does this compare with the Dielectric constants of other polymers? Make a bar-chart of Dielectric constant for Polymers to find out. Use a linear, not a logarithmic, scale and set the ranges to start from zero.
* What do “Dielectric constant” measure and “Maximum Service Temperature” measure? What bearing might they have on the non-stick question? (Try the information (“i”) link next to the property name on any materials record to access Science notes.)



## Discussion Point

The coating on non-stick saucepans is Teflon. Why does nothing stick to Teflon? And if Teflon is non- stick, how does it stick to the saucepan?

# What do Processes do to Properties?

Database: MS&E

The Process-Property Profile (PPP) data-table in the MS&E database allows charting of the effect of processing on properties. This project uses the PPP facility to explore solid-solutions.

* Open the PPP data-table from the home page and isolate Copper-Nickel alloys for exploration. (Chart/Select – Select from: Custom Define your own subset – Deselect all then open 1. Alloying and work hardening: copper alloys – select Copper-Nickel alloys)
* Make a chart with Young’s modulus on the y-axis and Copper content on the x-axis. Use linear scales for both. Set the axis range for Copper content (%) to run from 0 to 100. (To choose linear scales and set axis ranges first make the chart then double click on the axis name on the chart to bring up Axis settings. Click on “Linear” and use “Set” to adjust range.)
* Add a title using the Text label function (T) and draw a curve through the data using the Curve function (C) above the chart. Your modulus chart should now look like this.
* Now step through the mechanical, thermal and electrical properties in the same way, copying and pasting the charts into WORD to allow comparison. Follow the order

1. Yield strength,
2. Fracture toughness
3. Thermal conductivity
4. Thermal expansion
5. Heat capacity
6. Electrical resistivity

* Some properties (like Young’s modulus) vary with composition in an almost linear way. Which behave like this?
* Some, by contrast, show a much stronger dependence, with a maximum or minimum in the middle of the composition range – which are these?



## Discussion Point

Why does the Yield strength vary with solute concentration in the way shown in Chart 1? Got to the Home page, locate Science Notes, open Structure Science notes and open “Solid-solution strengthening” to find out.

Why does the Electrical resistivity vary with solute concentration in the way shown in Chart 6? Open the Structure Science note “Electron scattering” to find out. (Text and images can be copied from these Science notes by highlighting, copying and pasting into WORD.)

# Which elements form extensive solid-solutions with Cu?

Database: MS&E

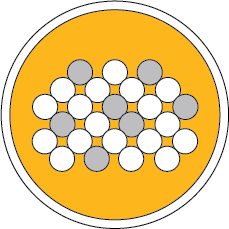
The Hume-Rothery rules set out criteria for the formation of extensive solid-solution:

1. Atom size difference less than 15%
2. Electronegativity difference less than 0.2

Strong influence

1. The components have the same crystal structure
2. The components have the same valence within

Less strong influence

The Elements data-table of the MS&E database contains data for all of these. Which elements would you expect to form an extensive solid -solution with copper?

* Select the ELEMENTS data-table from the Home page. Make a chart with atomic radius difference from copper (Atomic radius – Atomic radius of copper) on one axis and electronegativity difference from copper (Electronegativity – Electronegativity of copper) to find elements that are close to copper. (First look up the atomic radius and electronegativity of copper in the Copper record, then use the Advanced axis facility to make the functions in brackets above. Chose linear scales for both axes – double click on the axis name and select “linear” instead of “log”.)
* Apply a selection box centered on Copper with a width that is 15% of the atomic radius of copper on either side and differs from copper by an electronegativity of 0.075 above and below. List the elements appearing in the Results window. These meet the first two H-R criteria and will form extensive solid-solutions with copper.
* Complete solid-solubility across the entire composition range from 0 to 100% requires that the remaining two conditions are also met. Which of the elements in your list fulfill these additional requirements?
* The Phase Diagram data-table has diagrams for three copper alloys: Cu-Ni, Cu-Zn and Cu-Sn. What is the maximum solid solubility at the copper-rich side of each diagram? Are they consistent with the Hume-Rothery rules?



## Discussion Point

What is the entropy of mixing? What is its value for a mole of an alloy with a concentration c of atoms A and (1-c) of atoms B?

# Designing high-entropy alloys

Database: MS&E

High entropy alloys are solid-solutions with five or more components each with concentrations above 5%. The cumulative entropy of mixing reduces the free energy

of the alloy, stabilizing it and enhancing mechanical properties. The Hume-Rothery rules give guidance in selecting components that will form extensive solid-solutions:

1. Atom size difference less than 15%
2. Electronegativity difference less than 0.2

Strong influence

1. The components have the same crystal structure
2. The components have the same valence within

Less strong influence

The Elements data-table of the MS&E database contains data for all of these. Make a chart for selecting promising component-sets for high-entropy alloys.

* Make a chart for selecting promising component-sets for high-entropy alloys. Plot Electronegativity on the y-axis and Atomic radius on the x-axis. Use a linear scale for Electronegativity but retain the default Log scale for Atomic radius. (To change an axis from log to linear, double click on the axis name, then click on “linear” in the Axis settings box.)
* Recolor the elements to identify their crystal structure. (The best way to do this is to use a limit stage to select all the elements with a “Cubic, face centered” structure, highlight the resulting list, right click and select Record color, chose color, then repeat for the other structures.)
* Create a selection box with a width that corresponds to 15% change in atomic radius and a height that corresponds to a difference of 0.075 in electronegativity. Use this box to track across the array of elements on the chart, placing it over clusters to identify promising components. (Feel free to relax the constraints a little – we are only looking for a solubility greater than 5%, not total solid solubility.)
* Enclose each cluster with a line using the Curve tool in the tool-bar across the top of the chart. Label the encircled clusters, listing the elements they contain, using the Text label tool in the same tool-bar. How many promising clusters do you find?



## Discussion Point

High-entropy alloys are a new and currently-active field of research. Research “High-entropy alloys” on the world-wide web. What are their characteristics, properties and potential applications?

# Harvesting waste energy without regulatory risk

Database: MS&E

A maker of small sensors to be embedded in products that may not have access to electrical power hopes to power them by harvesting waste energy – thermal,

using thermoelectric materials, or kinetic, using piezo-electrics. The maker is risk-averse: materials containing “Restricted” elements or elements that appear on the “Critical” lists in Europe or the US are to be avoided. You are asked to do a survey of available materials and report back, flagging those to be avoided.

The Materials data-table of the MS&E database has records for thermo-electric and piezo-electric materials, including their composition. Draft a report that meets the makers remit. Before you start, make sure you know what is being asked.

* What are “critical” materials? Why would the sensor-maker wish to avoid them? (The records for Elements list “Critical materials information” and indicate if the element is on the EU or US Critical list. The science note (i) for these entries explain what “Critical” means.)
* What does “restricted” mean? Use the Internet to find elements listed under the Restriction of Hazardous Substances (RoHS) Directive. (Other nations have very similar restrictions).
* Why might the sensor-maker wish to avoid Critical or Restricted materials?
* Open the Materials data-table on the Home page and Browse to Functional materials – Semiconductors and thermoelectrics – Thermoelectrics to make a list of thermoelectric materials.
* Do the same for Piezo-electric material
* Annotate the two lists, indicating which materials are free from Critical or Restricted materials. (The links from the materials in the lists to the Elements data-table gives direct access to these elements. Their records report whether or not they appear on the US or EU Critical Lists.)



## Discussion Point

What is the WEEE directive? Would knowledge of this Directive be important to the sensor-maker?

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