IOP Institute of Physics

Energy

Energy in new GCSEs

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Introduction and summary

Summary

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Session objectives

- Engage in discussion of:
  - The need for change to the teaching of energy
  - The language of SPT – recommendations for a better way of talking about energy
  - A number of examples
  - Concerns about the language of SPT (or anything else)

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Session cautions

- Not a new theology
- Not the language police
- No quick fixes: not simply a linguistic change
- Stores are not essential but might be helpful

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Session structure

- 7 sections that each addresses a concern about energy teaching
  Labelled A to G
- Within each section, some related recommendations
  Also labelled A to G
- 16 suggestions for improving discussions

Summary

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Some of the new statements – GCSE criteria

- calculate the amounts of energy associated with a moving body, a stretched spring, and an object raised above ground level
- describe and calculate the changes in energy involved when a system is changed by heating (in terms of temperature change and specific heat capacity), by work done by forces and by work done when a current flows
- describe all the changes involved in the way energy is stored when a system changes, for common situations: appropriate examples might be an object projected upwards or up a slope, a moving object hitting an obstacle, an object being accelerated by a constant force, a vehicle slowing down, bringing water to a boil in an electric kettle

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Also what is not there

- Types (9)
- Transformations or conversions
- Dodgy definitions - capacity to do work; makes thing happen
- Electrical energy or sound energy (or any xxx energy)
- Stores

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Introduction and summary

Summary

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Specific concerns about '9 types' paradigm

Often, energy discussions:

A. give energy substance when it is a calculation tool
B. explain away useful and beautiful ideas
C. are ambiguous and inconsistent
D. employ spurious types
E. use heat in a caloric way
F. give causal powers to energy
G. ignore the second law

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Recommendations

A. i. Avoid implying - through language - that energy is a free-standing substance.
   ii. Relate energy to calculations and terms that can be quantified
B. i. Use physical processes and mechanisms, not energy, to investigate & explain phenomena
   ii. Look for a real cause of change – it won't be energy or 'transformations'
C. i. Don't get tied up with chains or distracted by un-calculable intermediates
   ii. Define a start and end point (or states)
D. i. Avoid spurious, invented 'forms' of energy (usually as intermediates - Ci)
   ii. Look for active 'ing' words to link the states (pathways)
E. Take care when using terms from thermodynamics:
   - it is safer to use heat as a verb and heating for the process
F. Differences cause change (and Bii)
G. i. Energy is not the capacity to do work
   ii. Introduce ideas around the second law, dissipation and waste

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Suggestions for improving discussions

1. Avoid dragging energy into descriptions of every process (to make them sound more physicsy)
2. Avoid phrases like 'energy released', 'energy lost', 'energy produced', 'energy running out'
3. Try to avoid asking questions or having discussions that are simply labelling exercises
4. Refer to gains and losses rather than flows, conversions and released.
5. Choose examples carefully – not every situation lends itself to an energy analysis or discussion
6. Avoid developing complicated energy-based descriptions of cases of dynamic equilibrium
7. Energy analysis discussions – even when qualitative - should relate to quantities that *can* be calculated
8. Try the three step approach to separate description, discussion/explanation and energy analysis
9. Separate the energy analysis from what happens in between; for the in between, ask questions and have discussions about mechanisms
10. Identify processes that involve working and calculate work done; or electrical working; or heating
11. Avoid using an unprincipled list of kinds of energy (sound, light, solar, electrical, heat)
12. Distinguish between stores (joules) and pathways (watts)
13. In thermal situations, distinguish:
    - that which is stored (thermal store) from the process of transfer (heating)
    - heating from raising the temperature
14. Use pathways to link states (working, electrical working, heating by particles, heating by radiation)
15. Identify examples in systems where a difference will lead to a change
16. Have discussion about dissipation, disorder, direction of time and the differences between heating and working.

A. Avoiding implying energy is a substance

Avoiding substantiation

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How easy is it? . . . to go wrong?!

What are the mental pictures conjured up by these descriptions?

- The moving pencil uses kinetic energy (QCA)
- The steam [from a volcano vent] is converted into energy and transported to Europe via a 1,200-mile sea-floor cable. (The London Paper)
- Carbonaceous matter is converted to heat or other forms of energy (Physics World)
- Energy makes things happen (ASE Big Ideas – 1st version)
- The bulb lights because energy flows from the battery to the bulb (Sophie, Year 9)

No wonder she is confused but the others should know better.

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Some early indications of problems

Energy, in energy descriptions, can be:

1. Used to make something sound scientific (and a bit intimidating)
2. Confusing – does not plant useful pictures in our head
3. Not a useful thinking tool
4. Reified – making it seem like a standalone substance ('release', 'flow')
5. Based on needs of assessment

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Recommendations

A. i. Avoid implying - through language - that energy is a free-standing substance.

Suggestions for improving discussions

1. Avoid dragging energy into descriptions or explanations to make them sound more physicsy
2. Avoid phrases like 'energy released', 'energy lost', 'energy produced', 'energy running out'

Avoiding substantiation

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If energy is so much trouble, why bother with it?

To do calculations

- How many Mars bars do I need to climb a mountain?
- How much coal/oil do I use in a day?
- When will the world's energy resources run out?
- Can the Sun supply us with our energy needs?
- How hot does a Cat Cracker have to be?
- Can the LHC create a Higgs boson?

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If energy is so much trouble, why bother with it?

To do calculations

Before we teach calculations, we need a language to discuss the amount of energy associated with a system and its configuration.

A test of the helpfulness (or point) of a discussion is whether you could add 'and the amount is . . .' in a meaningful way.

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Recommendations

A. i. Avoid implying - through language - that energy is a free-standing substance.
   ii. Relate energy to calculations and terms that can be quantified

Suggestions for improving discussions

4. Refer to gains and losses rather than flows, conversions and released.
5. Choose examples carefully – not every situation lends itself to an energy analysis or discussion
7. Energy analysis discussions – even when qualitative - should relate to quantities that *can* be calculated

B. Explaining without explaining away

Explaining without explaining away

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Labelling question

A microphone converts ________ energy to ________ energy

Does this:

- provide an explanation?
- help with understanding?
- allow us to drill down?

Or does it

explain away the physics, being the end of the story without really telling us anything useful about the situation.

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Labelling question

A microphone converts sound energy to electrical energy.

This tells us nothing about the mechanisms and provides no opportunity for further exploration.

Neither sound energy nor electrical energy have a physical referrant

Maybe the following description relates more directly to what is happening:

A microphone converts a sound wave into an electrical signal.

It is based on ideas with a physical referrant. Therefore, we can drill down into their detail: pressure, vibrations, sound waves, EM induction, electric current etc

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Recommendations

Bi. Use physical processes and mechanisms, not energy, to investigate & explain phenomena

Bii. Look for the real cause of change – it won't be energy or 'energy transformations'

Suggestions for improving discussions

3. Try to avoid asking questions or having discussions that are simply labelling exercises

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Explanations and calculations

1. You do work to lift a book from the floor to a table, by pulling against its weight.
2. Chemical energy in your body is used up and transferred to the book as gravitational potential energy.

1. Cubic water in a tank goes to tubular water in the pipes and cylindrical water in the glass.
2. The water tank is high up so the water's weight makes it flow down through the pipes into the glass when the tap is opened.

Which, of each pair, explains and which prepares for calculations?

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Suggestions for improving discussions

5. Choose discussion examples carefully – not every situation lends itself to an energy analysis
   (*Try* to avoid invoking energy in physical explanations)

C. Clarifying the analysis (Eliminating ambiguity) Start and end points

Clarifying the analysis

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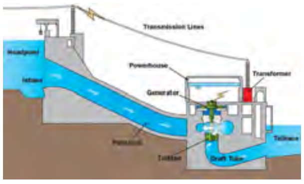
Another example

- A hydroelectric power station running:
- Tell an energy story
  - Compare answers:
- Are they the same?
- Is there a convergent, unambiguous result?
- What is the role of energy?



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Typically

Variation on:

- Some sequence with GPE -> kinetic energy -> electrical energy -> heat energy and sound energy

Concerns

- Explains away - masks all the processes and mechanisms
- No convergent, unambiguous story
- Water is moving; but KE has no role. No calculation.
- Spurious, made up energy terms: sound, heat and, yes, electrical.

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Eliminating ambiguity

1. By cheating

Fill in the blanks for a hydro electric power station:

Graviton all ____________ energy -> __________ energy -> electrical energy +

___________ energy and sound energy

Clarifying the analysis

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Eliminating ambiguity

2. More helpfully: by changing the analysis

Define a start point and an end point (well defined snapshopts):

Start: water stored at the top

End: water is at bottom;
some appliances have been run for some time;
the world is a little bit warmer.

Change in the energy profile of the system:
Gravitational potential energy of the system has been reduced
Or A gravitaional store associated with the system has emptied
A thermal store associated with the system has increased

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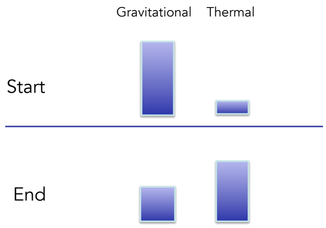
Graphically



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SPT and stores

Clarifying the analysis

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Recommendations

Ci. Don't get tied up with chains
or get distracted by un-calculable intermediates

CII. Define a start and end point – to make the analysis clearer and cleaner.

Use stores if you fancy it.

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Suggestions for improving questions

5. Choose examples carefully – not every situation lends itself to an energy analysis or discussion
6. Avoid examples that lead to chains or are simply not open to energy analysis
7. Energy analysis discussions – even when qualitative - should relate to quantities that *can* be calculated

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Try some examples

- A jumpy – squeezing it and letting go

- Define start and end
- How is energy stored at the start and at the end?
- What calculation could you do?

- Eating a Mars bar before climbing a mountain

- Define start and end
- How is energy stored at the start and at the end?
- What calculation could you do?

- Note: no mention of 'stores' - yet

Clarifying the analysis

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Energy stores

We need a language to describe how energy is stored at start and end points. It must:

- refer to an attribute (behavior or state) of the system that contributes to the system's total energy.
  For example, position in a field, motion, distortion and so on;
- allow us to calculate the change to the total energy of the system as a result of that attribute changing.
  For example lifting a book in a gravitational field, changing the speed of a tennis ball, stretching an elastic band and so on.

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Energy stores

SPT provides a language to describe how energy is stored at start and end points. A way that leads to calculations.

It is:
- an excellent teaching approach: consistent, complete and helpful;
- derived from evidence and thinking
- merely a teaching approach (not physics)

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Cii. 3 step approach

Clarifying the analysis

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An example

Driving from Hatfield to Birmingham

- Define start and end
- What is gained and lost
- What calculation could you do?

In terms of energy analysis, this is quite a dull story.
Energy does not tell us about either:

» The journey (purposeful: getting somewhere, scenic etc)
» The physical processes

This is relevant because it is easy to

» Drag the journey into the energy analysis (so as not to lose it from discussion)
» Drag energy analysis into the journey (to make it sound more physicsy)

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An example

Three step approach:

1. Description
2. Physical processes
3. Energy analysis

Note that 'working' and 'heating' may well appear in both 2 and 3.

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Try some examples

- A pull-back toy

1. Description
2. Physics discussion/explanation
3. Energy analysis:

- Define start and end
- How is energy stored at the start and at the end?
- What calculation could you do?

Clarifying the analysis

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Recommendations

Ci. Don't get tied up with chains
or get distracted by un-calculable intermediates

CII. Define a start and end point – to make the analysis clearer and cleaner.

CIII. (or well-defined snapshots)

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Suggestions for improving questions

8. Try the three step approach to separate description, discussion/explanation and energy analysis
9. Separate the energy analysis from what happens in between; for the in between, ask questions and have discussions about mechanisms

D. Pathways
Dii. Towards pathways

Pathways

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A clockwork motor lifts a weight

Before
- The elastic store empties

After
- A gravitational store fills up
- A thermal store fills up a little

What happens in between?

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Process 1: working

Before
- The elastic store empties

The spring is working (doing work)

After
- A gravitational store fills up
- A thermal store fills up a little

In SPT, one of our pathways: working

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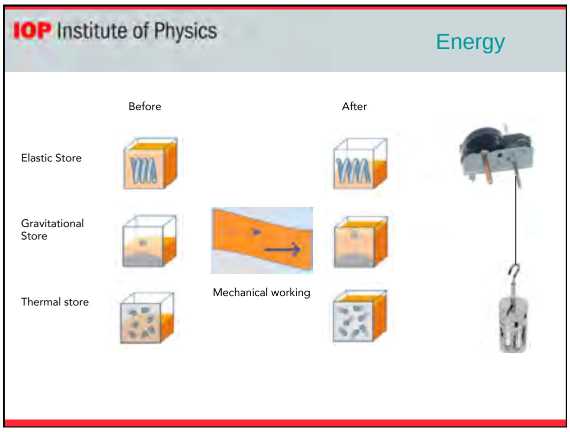
Transients/intermediates

- What is role of KE in this example?
- Is there a store of KE that would be useful in a calculation?

KE is transient and not relevant;
The spring is doing work against g.

What about:
- a spinning blade?
- the element of a kettle?
- an electric current?
  - More anon.

Pathways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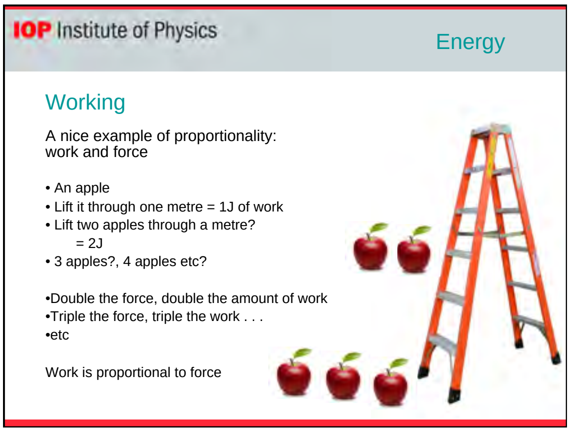
Energy
Before
After
Elastic Store
Gravitational Store
Thermal store
Mechanical working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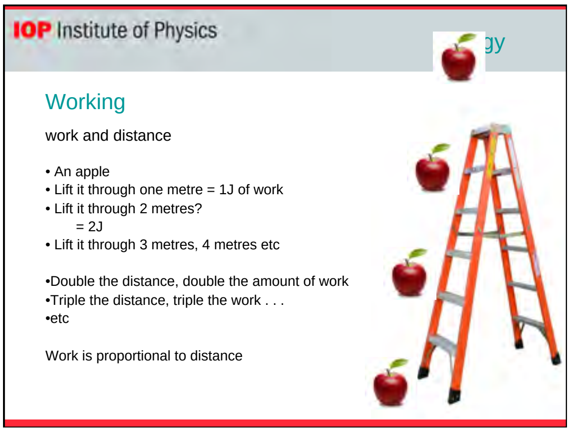
Energy
Working
A nice example of proportionality: work and force
• An apple
• Lift it through one metre = 1J of work
• Lift two apples through a metre?
= 2J
• 3 apples?, 4 apples etc?
•Double the force, double the amount of work
•Triple the force, triple the work . . .
•etc
Work is proportional to force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Working
work and distance
• An apple
• Lift it through one metre = 1J of work
• Lift it through 2 metres?
= 2J
• Lift it through 3 metres, 4 metres etc
•Double the distance, double the amount of work
•Triple the distance, triple the work . . .
•etc
Work is proportional to distance

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Recommendations

Ci. Don't get [ ] distracted by un-calculable intermediates

Dii. Look for active words to link the states

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Suggestions for improving discussions

9. Separate the energy analysis from what happens in between; for the in between, ask questions and have discussions about mechanisms
10. Identify processes that involve working and calculate work done
11. Avoid using an unprincipled list of kinds of energy (sound, light, solar, electrical, heat)

D. Pathways

Di. Avoiding spurious types (unprincipled lists of types)

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Other examples

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Tell a typical energy story for

1. Someone singing a short tune

Attempt 1

Chemical energy is converted to kinetic energy which is converted to sound energy and heat energy.

What is the role of kinetic energy?
Does it help prepare for a calculation?
Is there any sense of a store,
- of an independence of time?

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Energy

Tell a typical energy story for

1. Someone singing a short tune

Attempt 2

Chemical energy is transformed into sound energy which becomes heat energy.

What is the role of sound energy?
Does it help prepare for a calculation?
Is there any sense of a store,
- of an independence of time?

Pathways

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Tell a typical energy story for

1. Someone singing a short tune

Attempt 3

Our vocal chords make the air vibrate (by doing work on the air in our voicebox) and the vibration is carried out as a sound wave. The wave, in turn, does work on the walls, our ears etc, raising their temperature.

By working on the air, the chemical store associated with our body has depleted and the thermal stores associated with the walls, surroundings and our ears have filled a little.

Sound energy is a spurious form of energy made up by tacking 'energy' onto a perfectly good word to squeeze it into the paradigm.

It cannot be quantified
It has no equivalent term in an expression for total energy
Often time dependent

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Recommendations

Di. Avoid spurious, invented forms of energy

Dii. Look for active 'ing' words to link the states

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Suggestions for improving discussions

8. Try the three step approach

9. Separate the energy analysis from what happens in between; for the in between, ask questions and have discussions about mechanisms

11. Avoid using an unprincipled list of kinds of energy (sound, light, solar, electrical, heat)

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Tell a typical energy story for

1. Photosynthesis
2. A coal fire
3. A battery radio

Other spurious forms of energy made up by tacking 'energy' onto perfectly good words:

- Light energy/solar energy
- Heat energy
- Electrical energy/sound energy (oh yes . . . more anon)

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Tell a typical energy story for

1. Photosynthesis
2. A coal fire
3. A battery lighting a light bulb

In each case, consider what unit you would use to quantify the phenomenon

Watts
Not joules – they are not stores

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Recommendations

Di. Avoid spurious forms of energy

hints:

- they are usually transient or intermediate (i.e. they are not stored at start or end)
- they cannot be calculated/quantified
- they have no equivalent term in an expression for total energy
- they are often time dependent
- they are usually perfectly good words with energy added (sound, light, heat, electrical)

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Suggestions for improving discussions

12. Identify stores with quantities that can be measured in joules

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Another process and pathway

An electric motor lifts a weight

Before

Before

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Energy

Another process and pathway

An electric motor lifts a weight

Before
- The chemical store empties

Before
- A gravitational store fills up
- A thermal store fills up a little

Note: no role for kinetic energy
nor for electrical energy

What happens in between?

Pathways

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Another process and pathway

Process 2: Electrical working

Before
- The chemical store empties

  – The motor and circuit are doing electrical work

Before
- A gravitational store fills up
- A thermal store fills up a little

Electrical energy here has no referent.
There is no store; it is time-dependent
How fast do the electrons move?
What about a.c.?

In SPT, another of our pathways: electrical working

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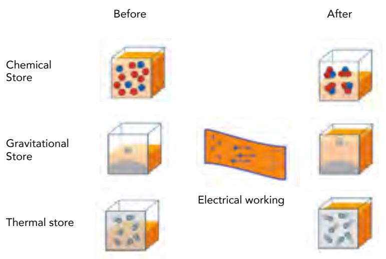

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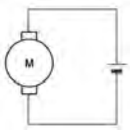
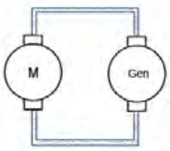
Electric circuit



Electric circuits are force transmitters not energy converters.

A bit like a bicycle chain.

Use a dynamo . . .



. . . and it's even more like a bicycle chain.

Would you talk about giving energy to links in the chain, which then hand it on?

Would you talk about an energy flowing through a chain?

Pathways

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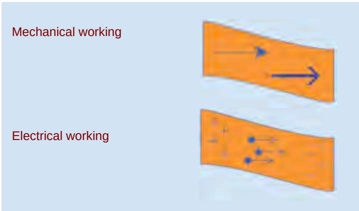
Two pathways so far – both working



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Recommendation

Dii. Look for active words to link the states

Suggestions for improving assessments

10. Identify processes that involve working and calculate work done; or electrical working; or heating
11. Avoid using an unprincipled list of kinds of energy (sound, light, solar, electrical, heat)
12. Distinguish between stores (joules) and pathways (watts)

E. Making heat (a verb)

Making heat (a verb)

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Making heat

- Heat rises
- Put the cake on a low heat in the oven
- Black clothes absorb heat better than white ones
- The heat on the Costa was too much to bare
- A saucepan is a good conductor; so the flame's heat passes through into the water.
- Friction generates heat
- A hamster loses its heat more quickly than an elephant because of its surface area to volume ratio.

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Making heat

Much of the problem is linguistic:

1. The word 'heat' is used to mean (at least) two things in physics discussions:
   That which is stored
   That which is transferred
2. We don't have a word for 'raising the temperature'
3. We don't have a good word for energy associated with random particle movements and positions.

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Making heat 1: stored and transferred

The word 'heat' is used to mean (at least) two things in physics discussions:
That which is stored
That which is transferred

Typically:

An insulated house keeps the heat in
A hamster loses heat to the surroundings
A tepid swimming pool has more heat energy than a pot of hot coffee because it has more particles.
An electric motor transfers energy to the surroundings as waste heat.
Hot coffee loses its heat to the surroundings

Making heat (a verb)

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Making heat 1: stored and transferred

Before
- Thermal/particle store (tea cup)
  - Particle collisions are heating the surroundings

After
- Thermal/particle store (surroundings)

A new pathway: heating (by particles)

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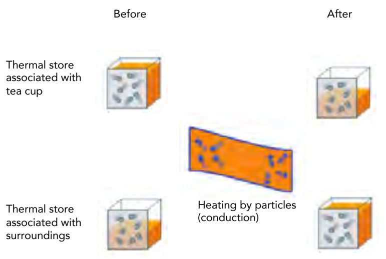

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Recommendations

Di. Avoid spurious forms of energy (heat)

D ii. Look for active 'ing' words to link the states (pathways): heating (by particles)

E. Take care when using terms from thermodynamics:
- it is safer to use heat as a verb and heating for the process

Making heat (a verb)

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Suggestions for improving discussions

11. Identify processes that involve working and calculate work done; or electrical working; or heating
12. Avoid using an unprincipled list of kinds of energy (sound, light, solar, electrical, heat)
13. Distinguish between stores (joules) and pathways (watts)
14. In thermal situations, distinguish:
    - that which is stored (thermal store) from the process of transfer (heating)
    - heating from raising the temperature

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Important distinctions

We don't have a word for 'raising the temperature'. But it is not 'heating'

Because:

» You can heat something without raising its temperature (phase change)
» You can raise the temperature without heating it (doing work)

- Heating – the transfer energy due to a temperature difference
- Raising the temperature – can be achieved by heating or working

Typically (erroneously):

Friction heats the surface of our hands when we rub them

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Raising the temperature

Working to raise temperature
Note: Not converting work to heat: they are both processes

Making heat (a verb)

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Joule experiment

- Lingering interpretation:
  - “The Joule experiment demonstrated the mechanical equivalence of heat”
  - Continues to give substance to heat (presumably because of caloric)
- Better description/interpretation
  - it showed that there are two ways of raising the temperature of something (or increase its thermal energy): heating it or working on it.
- I.e. the first law of thermodynamics.

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Suggestions for improving discussions

13. In thermal situations, distinguish
    - heating (the process) from
    - raising the temperature (which can occur through heating or working

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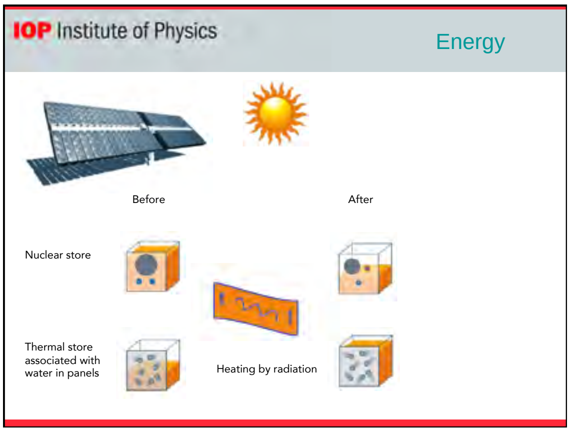
Aside: looks like we have the first law

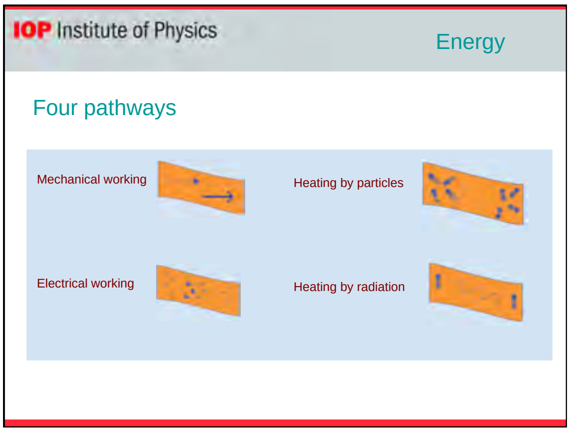
dU = dW + dQ

Two ways of raising internal energy:

- Working
- Heating

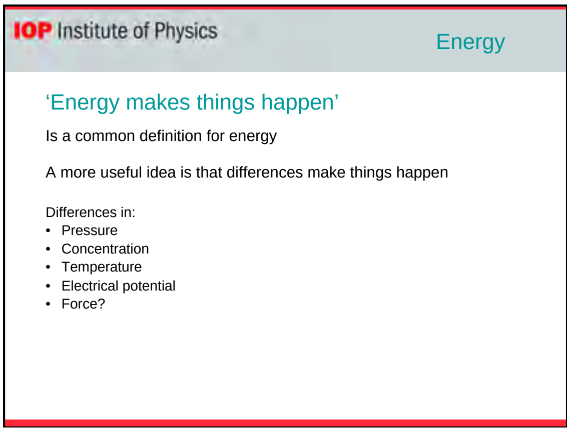
Making heat (a verb)

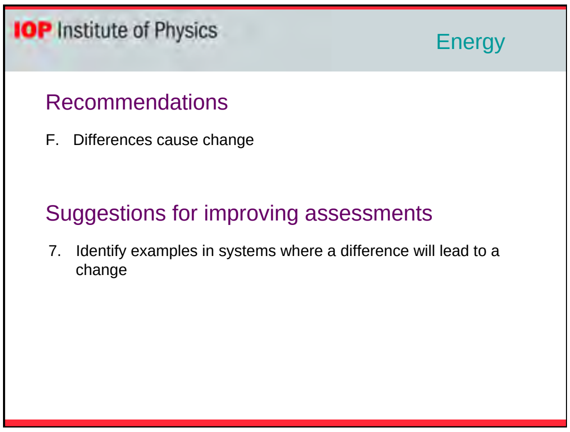




F. Difference and change

F. Difference and change





G. Dissipation and waste

G. Dissipation and waste

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The difference will tend to even out

It is not energy that runs out but the difference.

It is not conservation of energy that we are battling against but increasing disorder or entropy.

Another common definition of energy is
“the capacity to do work”

This cannot be right because energy is conserved but the capacity to do work is not.

This definition is for ‘free energy’ – an underused term that is useful because it relates to people’s experience. Free energy does get used up.

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Dissipation and waste

Dissipation is inevitable; waste is avoidable.

Dissipation
•Whenever there is heating, dissipation is inevitable and the process is not reversible (with some very theoretical exceptions)

Waste
•A process that involves only work can be reversible
•However, if work raises the temperature, then heating will occur (of the surroundings) and the process cannot be reversed; this is wasteful
•Reducing waste is about reducing temperature rises from work

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Recommendations

G. i. Energy is not the capacity to do work
ii. Introduce ideas around the second law, dissipation and waste

Suggestions for improving discussions

15. Identify examples in systems where a difference will lead to a change
16. Have discussion about dissipation, disorder, direction of time and the differences between heating and working.

Summary

Summary

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Energy

Recommendations

A. i. Avoid implying - through language - that energy is a free-standing substance.
   ii. Relate energy to calculations and terms that can be quantified

B. i. Use physical processes and mechanisms, not energy, to investigate & explain phenomena
   ii. Look for a real cause of change – it won't be energy or 'transformations'

C. i. Don't get tied up with chains or distracted by un-calculable intermediates
   ii. Define a start and end point (or states)

D. i. Avoid spurious, invented 'forms' of energy (usually as intermediates - Ci)
   ii. Look for active 'ing' words to link the states (pathways)

E. Take care when using terms from thermodynamics:
   - it is safer to use heat as a verb and heating for the process

F. Differences cause change (and Bii)

G. i. Energy is not the capacity to do work
   ii. Introduce ideas around the second law, dissipation and waste

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Energy

Suggestions for improving discussions

1. Avoid dragging energy into descriptions of every process (to make them sound more physicsy)
2. Avoid phrases like 'energy released', 'energy lost', 'energy produced', 'energy running out'
3. Try to avoid asking questions or having discussions that are simply labelling exercises
4. Refer to gains and losses rather than flows, conversions and released.
5. Choose examples carefully – not every situation lends itself to an energy analysis or discussion
6. Avoid developing complicated energy-based descriptions of cases of dynamic equilibrium
7. Energy analysis discussions – even when qualitative - should relate to quantities that *can* be calculated
8. Try the three step approach to separate description, discussion/explanation and energy analysis
9. Separate the energy analysis from what happens in between; for the in between, ask questions and have discussions about mechanisms
10. Identify processes that involve working and calculate work done; or electrical working; or heating
11. Avoid using an unprincipled list of kinds of energy (sound, light, solar, electrical, heat)
12. Distinguish between stores (joules) and pathways (watts)
13. In thermal situations, distinguish:
    – that which is stored (thermal store) from the process of transfer (heating)
    – heating from raising the temperature
14. Use pathways to link states (working, electrical working, heating by particles, heating by radiation)
15. Identify examples in systems where a difference will lead to a change
16. Have discussion about dissipation, disorder, direction of time and the differences between heating and working.

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Energy

17. Use the SPT approach

e can describe energy changes - in a way that leads to culations - with 8 stores and 4 pathways.
://supportingphysicsteaching.net/EnHome.html
http://supportingphysicsteaching.net/EeHome.html