PhysicsFactsheet

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Feedback

You step nervously forward to deliver your presentation. Gingerly you pick up the microphone, bristling with glowing LEDs. Gathering your courage you look out at the expectant audience, switch the microphone on and SCREEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE.....

An unearthly screech fills the room. Everyone winces and covers their ears. You have fallen victim, like so many before you, to the dark side of FEEDBACK!

What Is Feedback?

So what went on here? The job of the microphone is to detect sound and convert it to an electrical signal. The job of the amplifier is to make this electrical signal larger. The job of the loudspeaker is to convert this amplified electrical signal back into sound.

Of course, these sound waves can themselves be picked up by the microphone. So the output signal from the loudspeaker *feeds back* into the input – the microphone. Hence the name! Feedback is present whenever the output of a system controls part of the input to that system.

Positive Feedback

In positive feedback, a change in the input produces a change in the output which will *reinforce* that change. If there is only a little positive feedback (e.g. the microphone only picks up a small fraction of the output of the loudspeaker) it will lead to a slightly larger effect than anticipated. But if there is *enough* positive feedback it can lead to a *runaway* situation in which the output rapidly moves to the *maximum* (or minimum) that it can possibly produce. Our screeching loudspeaker is an example of this.

Negative Feedback

In negative feedback, changing the input produces a change in the output which will work *against* the original change.

The photo shows a *centrifugal governor* (a variant called a Pickering Governor). It would have been linked to the driveshaft of a steam engine and its purpose was to ensure that the engine ran at a steady speed.

The heavy balls are attached by springy metal to the central shaft. The faster the engine goes, the more rapidly the shaft spins, which flings the masses outwards.

Question 1: Why is this?

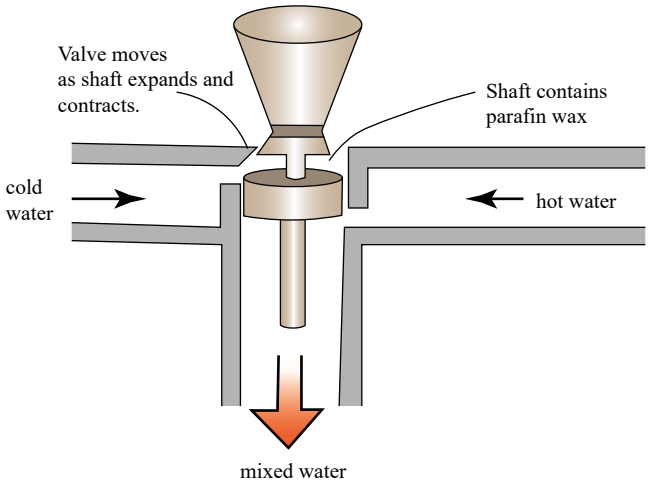
As the masses move out, the metal springs bend. This pulls on a linking mechanism, causing a valve to move and partially close off the supply of steam coming into the engine. The mechanism is arranged so that as the balls spin out, they close off the steam inlet pipe. This reduces the speed of the engine – that is, it works *against* the original change.

Question 2: Describe what will happen if the steam pressure drops a little, so that the steam comes in at a slower rate than before.

Once you grasp the idea of feedback you realise that it is all over the place. This factsheet contains a few examples, but you will think of many more as you work through it.

Mixing Valve

You can see these valves in showers, heating systems, and many other places where cold and hot water have to be mixed. Paraffin wax in the middle shaft expands when it's hot. This pushes the valve down and allows more cold water into the system. The reverse happens if the temperature drops.



Question 3: What is the overall effect?

Stability and Centre of Gravity

This little truck has its centre of gravity roughly at the bottom of the maker's logo. When tipped a little like this, the truck returns to its upright position.

But if tipped further, it doesn't!

Question 4: Why the difference?

The first case is an example of *negative feedback.* A small change in the angle leads to an effect which will work to *reduce* this change.

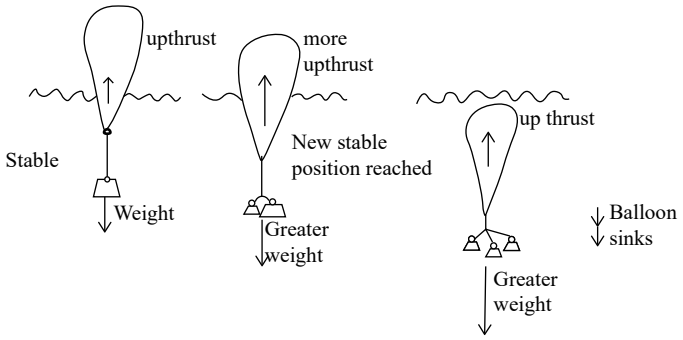
But in the second case we have *positive feedback.* The effect of the small change will be to *reinforce* that change and make it bigger.

Note that in this case we have a *transition* between negative and positive feedback. If the tilt stays below a certain level, we have negative

feedback, leading to stability. But once we go past this point we have positive feedback, which in this case produces instability. This change happens very suddenly.

Air-filled Float

Here is another example of a change from negative to positive feedback. Can you explain what is going on?



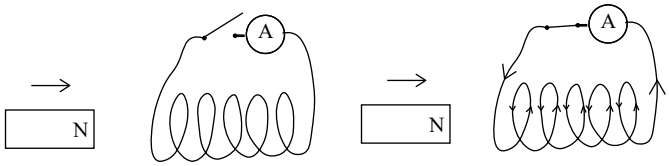
In the first case, if the float sinks further the buoyancy force (or "upthrust") will increase.

Question 5a: Why? Is this an example of negative or positive feedback?

But in the second case, as the float sinks the buoyancy force will decrease.

Question 5b: Again, why? And is this positive or negative feedback?

Electromagnetism and Lenz's Law



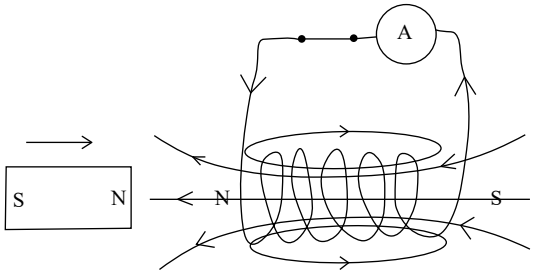
As the magnet on the left moves into the coil on the right, an e.m.f. (i.e. a voltage) is created across the terminals. If the switch is closed, the ammeter will show a reading. If the magnets were strong enough, you could light a small lamp or drive a little motor.

However, after the switch has been closed, you will find that it becomes *more difficult* to push the magnet towards the coil.

Question 6a: How could you explain this in terms of the law of conservation of energy?

The obvious question, however, is "How does it know?" Coils don't read physics factsheets and aren't aware that they ought to be conserving energy

Consider the current produced in the coil. It will produce its own magnetic field – it becomes an electromagnet. It will develop a north pole at the left and a south pole at the right, as shown.



Question 6b: Explain why this means that work has to be done to push the magnet towards the coil.

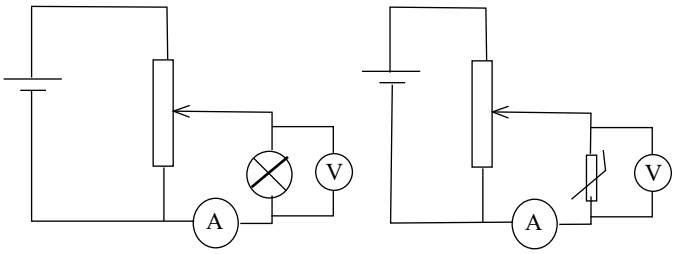
Question 6c: What would happen if the magnet were pulled away from the coil instead?

This is another example of *negative feedback.* The output (the current in the coil) tends to *decrease and damp down* the input (the movement of the magnet). This is an example of *Lenz's law*, often expressed: "The direction of an induced current is such that it will oppose the change that produced it."

This is why power stations, most of which use electromagnetic induction to generate electricity, require a mechanical source of power (wind, falling water, steam generated by the heat from coal, oil, or nuclear reactions) in order to keep their generators spinning. You can't produce an electrical current without putting mechanical work in.

This might seem annoying, but consider the alternative. If the current induced were the *other* way, reinforcing the input change (i.e. *positive* feedback), any increase in the current through a coil would generate an increasing magnetic field which would increase the current further. The change would become more and more rapid; the current would tend to infinity and the coil would be destroyed. Since an orbiting electron could be considered a sort of current loop, atoms would become unstable, matter would blow apart, and the universe as we know it would come to an end. Maybe Lenz's law isn't so bad after all!

Electronic Systems



The circuit on the left is often used to measure the voltage-current characteristics of a light bulb. We can adjust the rheostat to change the potential difference across the light bulb, and record the readings on the voltmeter and the ammeter, which we then use to plot a graph of V against I.

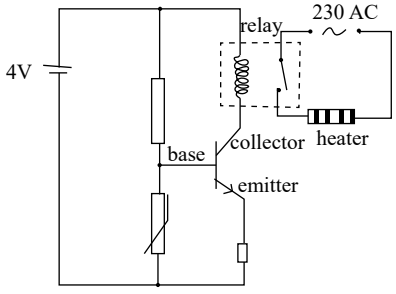
We might try to use the similar circuit on the right to investigate the characteristics of a thermistor.

Question 7a: What happens to the resistance of a thermistor as it heats up?

Question 7b: Suggest what might happen if you carried out this experiment.

Question 7c: Is this an example of positive or negative feedback?

On the other hand in this circuit the thermistor and the variable resistor *form* a potential divider.



Question 8a: What will happen to the voltage across the thermistor as the temperature drops and why?

If you have not met *transistors* before, they can be thought of as a kind of electronic switch. When the voltage between the points labelled "base" and "emitter" rises high enough, the transistor will switch on. A small current flows from base to emitter and a rather larger one from collector to emitter.

This current will switch on the *relay*.

Question 8b: How does a relay work and why is one required here?

The heater now comes on and the room warms up.

Question 8c: Explain what will happen to the temperature in the room and what sort of feedback is occurring.

Feedback and Climate Change

Feedback effects are important in the analysis of climate change.

Example 1: Ice is highly reflective and will tend to reflect a large proportion of the sunlight incident on it back into space. We say it has a high *albedo*. But as global temperatures rise, this ice will tend to melt. Example 2: On the other hand, clouds also have a high albedo. High temperatures lead to more evaporation from the oceans, and perhaps a higher rate of cloud formation.

Question 9: Do these two examples produce positive or negative feedback – and why?

Video Feedback

Feedback can give rise to more complicated situations than these. A closed-circuit video camera is attached to a screen that displays what the camera sees. What if the camera is now pointed at the screen? The image on the screen will contain a picture of the screen, which will itself contain a picture of the screen… and so on, *ad infinitum*. There is a positive feedback effect here, but there are a number of complicating factors: the screen will only form part of the camera's field of view, the camera may have an automatic white balance or brightness control, or the camera may be tilted so that the picture on the screen is rotated. This can give rise to intricate patterns, sometimes stable and sometimes constantly changing – feedback can give rise to *chaotic behaviour*.

Feedback in Biology

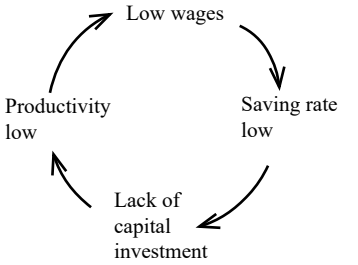
Feedback is such a fundamental concept that it can be found in all sorts of disciplines.

Living creatures tend to need their bodies to stay within a narrow range of conditions in order to survive. This is called *homeostasis* and there are a number of feedback mechanisms the body uses to accomplish this. For example, when you are dehydrated your pituitary gland produces ADH (anti-diuretic hormone), which stimulates your kidneys to remove less water from the blood and produce less, more concentrated urine. When there is plenty of water in the body the level of ADH drops and a higher volume of urine is produced.

Question 10: Is this an example of negative or positive feedback?

Feedback in Social Sciences

In geography and social sciences *vicious and virtuous circles* are often encountered. Here are two examples: the first from economics, the second from education!



Vicious circle: poverty in a low wage economy.

Virtuous circle: the successful learner!

Question 11: Are these examples of positive or negative feedback?

Answers

1. In the rotating frame of reference, you can think of this as centrifugal force flinging the balls out. If you want to stay in the lab frame, you can say that the centripetal force of the springs is not sufficient to provide the acceleration towards the centre necessary to keep them moving in such a tight circle.
2. If the steam pressure drops a little, the weights will be pulled in somewhat by the springs, since the centripetal forces is *greater* than that necessary to keep them moving in their current position. This will allow the valve to open; more steam enters and brings the engine speed back up.
3. The overall effect is to keep the water temperature constant; negative feedback.
4. Remember that the weight force acts down from the centre of gravity. In diagram 1 this will produce a clockwise moment (turning effect), pushing the truck back towards the upright position. But in diagram 2 it will produce an anticlockwise moment, pushing it away from its stable position tipping the object over.

5 (a) As the float sinks lower in the water, it displaces more water. Archimedes' Principle states that the upthrust is equal to the weight of fluid displaced. So the upthrust will increase until it balances the total weight. The object will stop sinking; negative feedback.

(b) Water pressure increases with depth. So as the float descends, it will be squashed by the water pressure and its volume will get smaller. It will then displace *less* water and the upthrust will be reduced. It will thus tend to sink further and faster; positive feedback.

6. (a) The lamp requires electrical energy, which it converts to heat energy and light energy. Since energy cannot be created from nothing, you must put in energy in the form of mechanical work.

(b) You will now have to apply a *force* to keep the magnet moving towards the coil in the face of the repulsion. To move the magnet a small distance will thus require *work* – work equals force times distance. (To be more mathematically exact, you would have to integrate force with respect to distance to get the total work done).

(c) In this case the induced current would be in the opposite direction. This would produce a south pole on the left-hand side of the coil and this would *attract* the magnet. But since you are now trying to pull the magnet away, you still have to *do work* to make this happen. Once again, the induced current *opposes* the change that brought it into being – Lenz's law and negative feedback again.

7. (a) A thermistor's resistance drops as it heats up.
   (b) You find that as the current through the thermistor rises, it heats up the thermistor. This tends to reduce the resistance of the thermistor, increasing the current further. If the current rises above a certain level, this effect will become stronger and stronger (thermal runaway) and the thermistor will be destroyed.
   (c) This is positive feedback.
8. (a) The thermistor's resistance grows as the temperature drops. Because the current into the base of the transistor is low, the resistor and thermistor form a potential divider. The voltage across the thermistor increases and this will switch the transistor on.
   (b) The current through the transistor is nowhere near large enough to run the heater. But as it runs through the relay coil it creates a magnetic field, which causes the relay switch to close. This completes the circuit connecting the 230V a.c. mains supply to the heater.
   (c) The temperature in the room should remain about the same, since when it heats up the thermistor's resistance will drop. The voltage across it will drop too, switching off the transistor and relay. The relay switch will open and the heater will be turned off. This is negative feedback.
9. The first case is positive feedback – when the ice melts, more sunlight will be absorbed and temperature will rise further. The second case involves negative feedback – the clouds will reflect extra sunlight and this will tend to reduce the temperature change.
10. The water level in the blood is kept stable – this is negative feedback
11. Both these cycles are self-reinforcing – they are both examples of positive feedback, even though one is malign and the other is beneficial.

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