Unit title	The test tube Stirling Engine and Thermodynamic cycles
Topic	Thermodynamics, Engineering
Name and email address of person submitting unit	Matt Chessher Mches34742@aol.com
Aims of Unit	This unit requires students to calculate work and efficiency related to the principles of thermal dynamics which underpin the Stirling engine.
Indicative content	This unit consists of a presentation with embedded questions and problems which challenge pupils to commit several calculations.
Resources needed	Pupils will require either the whole presentation as a hard copy or as an electronic version.
Teachers notes	An advanced practical activity for 16+ pupils perhaps covering several hours. To answer these questions pupils will be required to consider abstract concepts, perform calculations and write descriptively. Learning outcomes for this activity All students will be able to discuss the movement of thermal energy in terms of systems. Particularly the steam engine and water wheel example. Most students will with a little assistance be able to complete the participant activity tasks which are embedded within the presentation. Some students will unaided be able to work through the presentation unaided completing the tasks and gaining an insight into the working of the system in terms of thermal flow

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Date:	Topic: Thermodynamic Cycles	Time: 2 hours	Class: 16+

SEN pupils	Gifted and Talented	Class Room Support

Equipment needed for this activity:

Students will need access to the presentation in either electronic or hard copy form.

Health and Safety:

None

Learning outcomes for this activity

All students will be able to discuss the movement of thermal energy in terms of systems. Particularly the steam engine and water wheel example.

Most students will with a little assistance be able to complete the participant activity tasks which are embedded within the presentation.

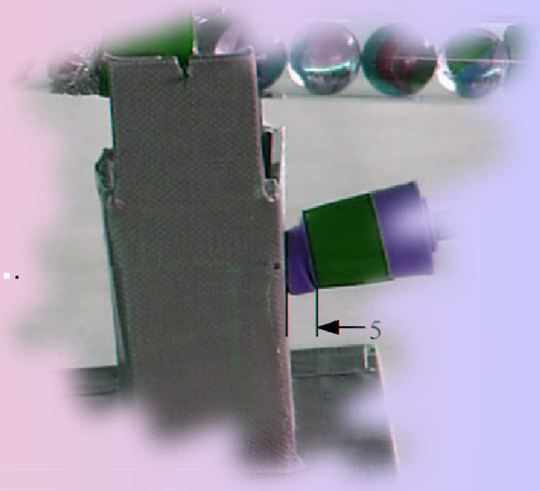
Some students will unaided be able to work through the presentation unaided completing the tasks and gaining an insight into the working of the system in termals of thermal flow.

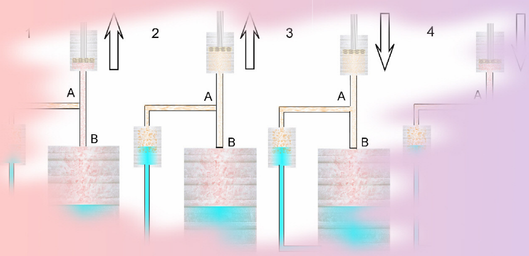
Starter Activity
Main Activity During this activity students follow a presentation on thermodynamics and engine systems. There are opportunities for class discussions and questions and tasks are embedded within the text.
Plenary Activity

Reflections on the lesson

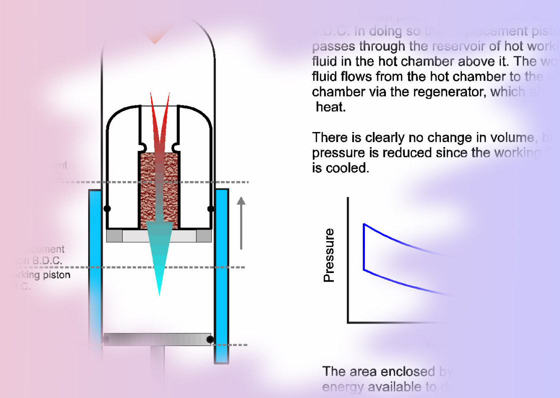
PromoteMSc

The Test Tube Stirling Engine.....





...and Thermodynamic Cycles



Contents

Caloric

In 1808 John Dalton concisely summarised the accepted notion of heat as follows:

"The most probable opinion concerning the nature of caloric, is, that of its being an elastic fluid of great subtility, the particles of which repel each other, but are attracted by all other bodies'.

A New System of Chemical Philosophy (Manchester, 1808)

They believed that heat was a substance called *caloric*. Its ability to repel itsel would explain heat transfer. It you hit, or rubbed, materials you would squeeze the caloric out. This would explain, for example, how friction will cause heat.

The calorists were able to account for a number of phenomena and the caloric theory could be applied to the numeric calculations of relations involving such quantities as specific heat and the velocity of sound in gases. A variety of experiments confirmed these calculations.

The industrial revolution was demanding a better understanding of steam engines.
What could be their maximum efficiency?

Sadi Carnot

Carnot published *Reflections on the Motive Power of Heat and on Machinery Appropriate for Developing this Power* in which he made comparison between the work extracted from a steam engine and that from a water wheel. At the time an adherent to the Caloric Theory, he believed that caloric 'fell' from high temperature to low temperature.

Student Activity 1

Discuss Carnot's analogy between the steam engine and the water wheel.

He recognised that the processes in a steam engine were cyclical and, in principle, reversible. Let's consider an idealised view of the steam engine. It is essentially a cylinder with piston connected to a boiler. The flow of steam is controlled by a system of valves.

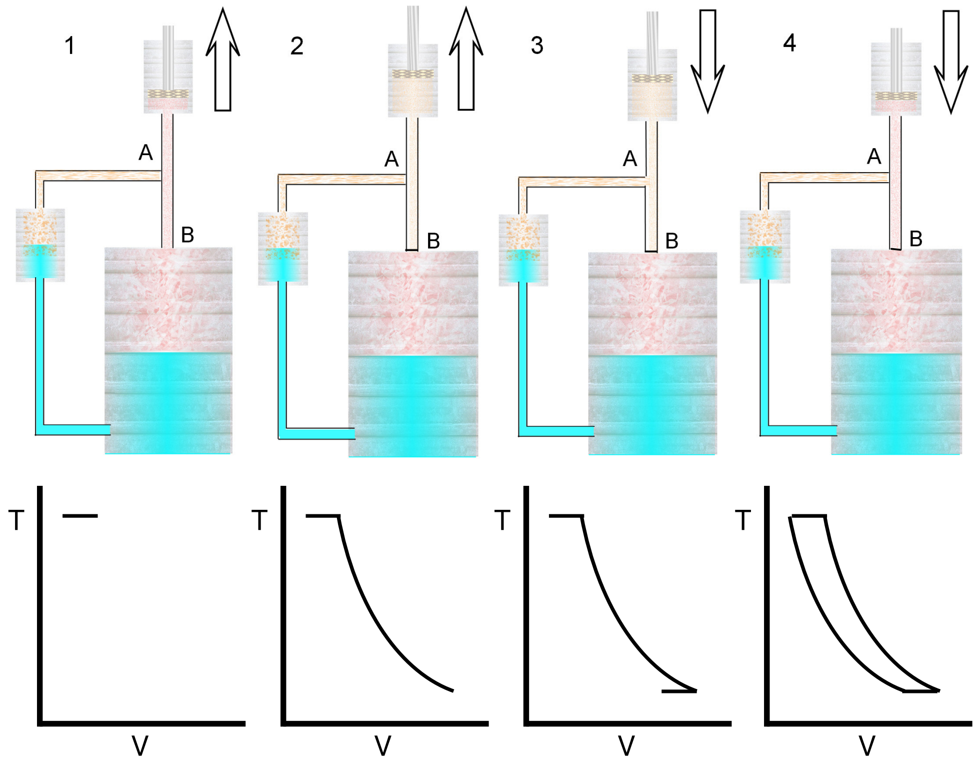


Fig. 1. Idealised schematic of the steam engine and thermodynamic cycle.

1. Valve 'A' is shut and valve 'B' open. Hot, high-pressure steam drives the piston up. This expansion is at constant temperature and is termed an *isothermal* expansion.

   ☹ Why does it remain at constant temperature? Shouldn't the expansion cause cooling?

   ☺ Fresh steam entering the cylinder provides the necessary energy to replace that which has been lost by molecules striking the piston.

2. Both valves are shut. The hot steam still has the energy to drive the piston up. Now there is no fresh input of steam and the temperature falls during the expansion. Expansion at constant heat is termed *adiabatic*.

3. Valve 'A' is opened and the returning piston pushes steam into the condenser. This is an isothermal process.

4. Both valves are shut and the residual cool steam is heated adiabatically by compression. The machine returns to its initial thermodynamic state.

Steam need not be the working fluid. It could be air, carbon dioxide, really anything that can transfer heat. Fig. 2. Illustrates the theoretical Carnot Cycle for helium for a machine working under specified conditions.

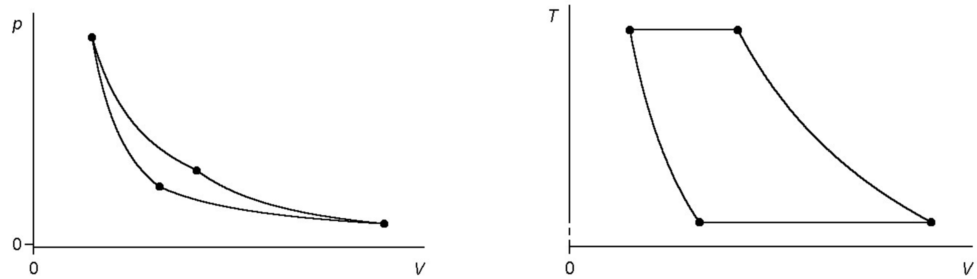


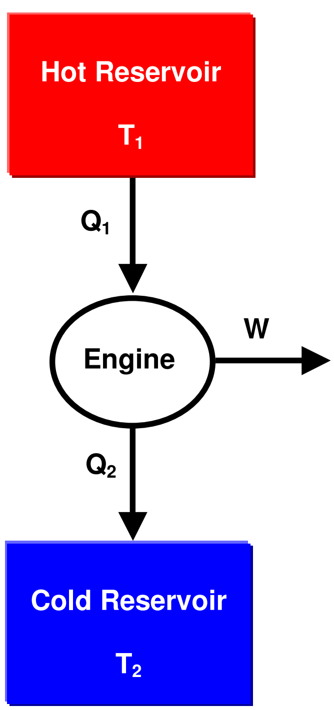
Fig. 2. A theoretical Carnot Cycle generated by the Simtherg simulation program. The working fluid is helium operating between 1 and 10 bar and between temperatures of 300 and 500K.

Participant Activity 2

1. Show that the work done by a gas at constant pressure 'P', expanding through a volume 'V' is simply the product of pressure 'P' and volume 'V'. [Hint: Work from the basic definitions of work, pressure and volume]

2. Sketch the PV indicator diagram of fig. 2. Shade the relevant area that represents the work done by the machine and the work done to the machine.

3. What is the relevance of the difference between these areas?



In essence heat flows from a high temperature reservoir to one of lower temperature. Some of the heat is converted to work by the engine.

In the ideal engine work done, $W = Q_1 - Q_2$. Efficiency is defined as the ratio of work done by the machine to heat absorbed from the high temperature reservoir.

So, efficiency, $E = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$

Another, and more famous, expression for efficiency is

$$E = \frac{T_1 - T_2}{T_1}$$

Remarkably the theoretical maximum efficiency of the ideal Carnot machine depends only on temperature, not on working fluid or details of the engine!

Running in reverse the input work, W, will drive heat against the temperature gradient - the machine acts as a refrigerator.

The Carnot cycle offers the best theoretical efficiency we can expect from a heat engine. Unfortunately there is no way to realise a practical Carnot engine! We look for cycles that get close. One such cycle is the Stirling cycle, patented in 1816 by Robert Stirling, a clergyman. His machine was more efficient than the steam engines of the time, and not so likely to explode!

☹ Wait a minute! Surely a machine of this antiquity is of little use to us today?

☺ Stirling machines are exciting much interest today. They offer the possibility of 'green refrigeration', their use in countries with high sunshine yields could lead to cheap local electricity. Nasa have shown interest in them and at least one group even imagine gliders powered by them!

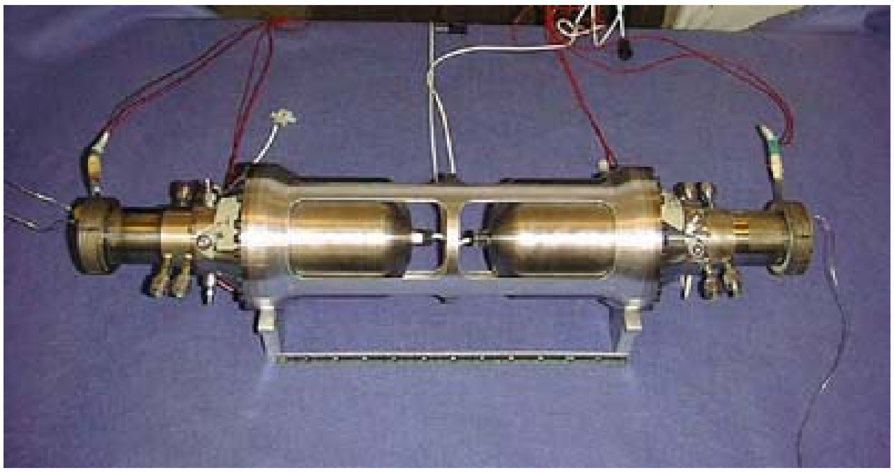


Fig.2. Opposing 55 W Stirling engines developed by NASA to run from radioisotopes providing energy for the hot reservoir.
From http://www.grc.nasa.gov/WWW/tmsb/stirling/doc/stirl_radisotope.html accessed April 2004

☹ Won't the machine need a flywheel - only a part of the cycle delivers power?

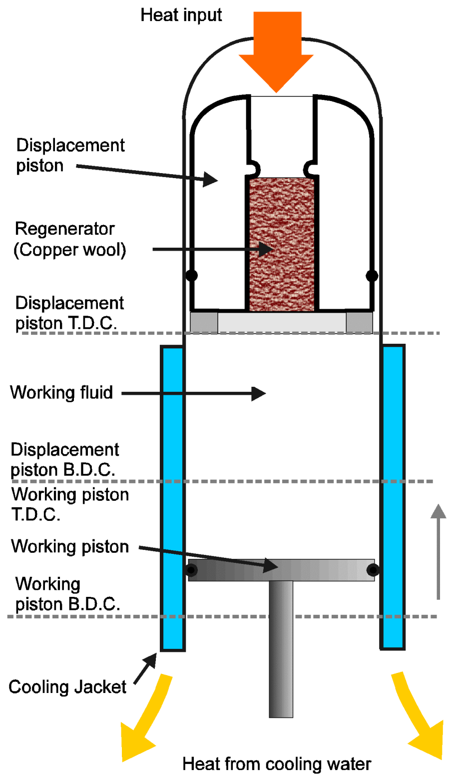
☺ Good point, but that's the reason for the opposing motor. One motor, during its power stroke drives the other through the rest of its cycle. More power without the weight of a flywheel!

Practical Stirling machines are highly engineered but it is possible to make them from rather simple materials. I want you to make one from a boiling tube, marbles and odds and ends!

I found this particular design at the website of the Stirling Cycle Research Group, Department of Mechanical Engineering , University of Canterbury. http://www.mech.canterbury.ac.nz/research/stirling/stirling.htm

First, though, read about how a Stirling engine works. You'll need to know that Stirling engines have two pistons. One delivers power (the working piston), the other displaces the working fluid from the hot side of the engine to the cold and back the other way again. This is the displacement piston.

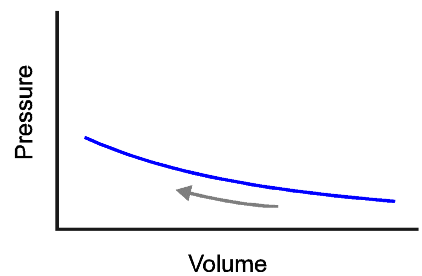
How a Stirling Engine Works

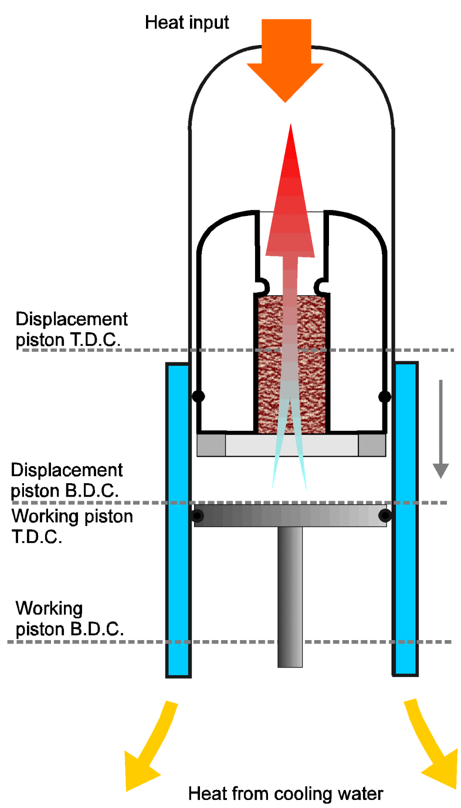


Stirling Cycle

At this point in the cycle the displacement piston is stationary at top dead centre. The working piston is moving upward largely compressing the working fluid (air) in the space between the displacement piston and the working piston.

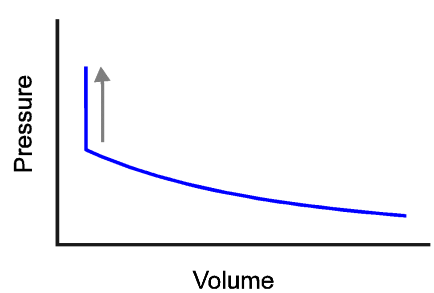
You would expect that this compression would cause a rise in temperature. However, heat loss through the cooling jacket ensures that the temperature remains constant during this compression. A change of pressure and volume at constant temperature is an ISOTHERMAL CHANGE. This change of state is illustrated on the PV diagram below.

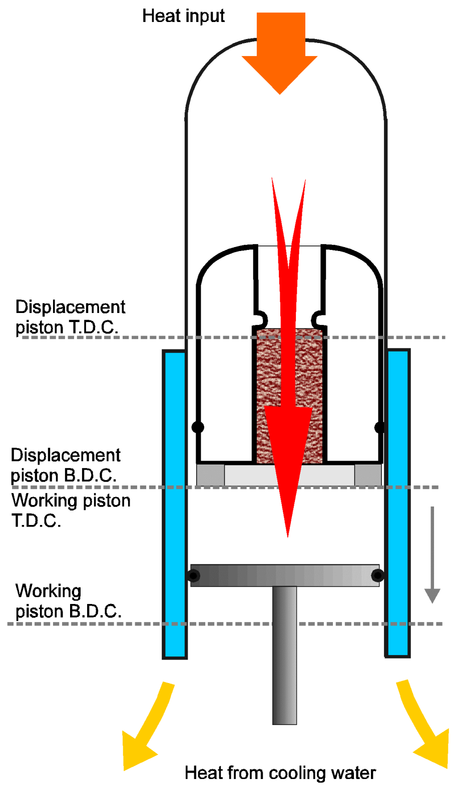




In an ideal Stirling engine the working piston remains stationary at T.D.C. during this phase in the cycle. The displacement cylinder moves down from its T.D.C. to its B.D.C. During this movement the working fluid is 'displaced' into the heated chamber. Heat is transferred from the regenerator to the working fluid during its displacement to the hot chamber. Transfer from the regenerator is incomplete and the heater must make good this deficit.

This change of state takes place at constant volume, yet pressure increases since the working fluid has been heated. Such a change of state is termed ISOCHORIC.

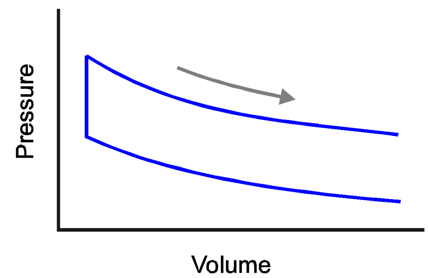


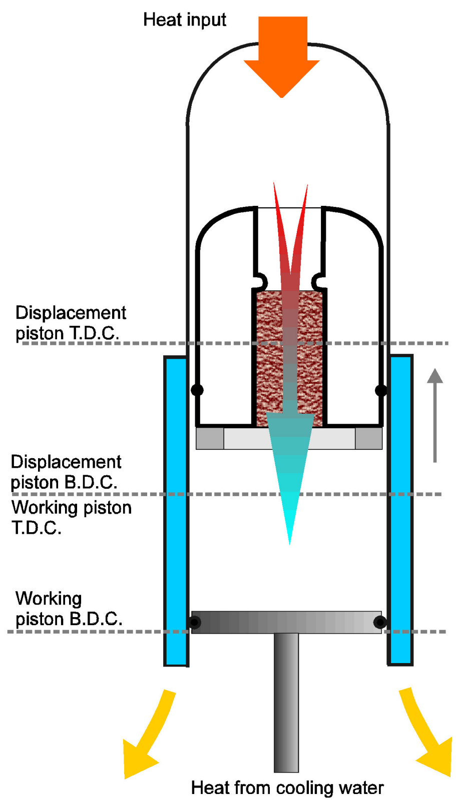


Working Stroke:

As before we consider the ideal engine. During this phase the displacement piston remains stationary. The working fluid is now in the heated end of the cylinder and expands. It flows through the regenerator and pushes the working piston downward.

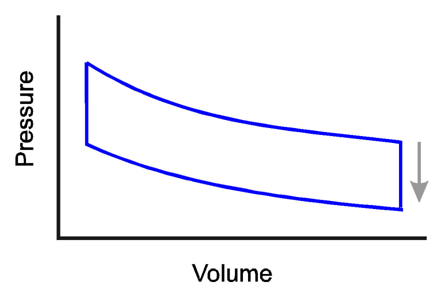
Energy input from the heater ensures that this expansion is isothermal.





The working piston remains at B.D.C. as the displacement piston moves up from B.D.C. to T.D.C. In doing so the displacement piston passes through the reservoir of hot working fluid in the hot chamber above it. The working fluid flows from the hot chamber to the cool chamber via the regenerator, which absorbs heat.

There is clearly no change in volume, but the pressure is reduced since the working fluid is cooled.



The area enclosed by the cycle represents energy available to do external work.

Student Activity 3

Distinguish between Adiabatic, Isothermal and Isochoric changes

The Test-Tube Stirling Engine

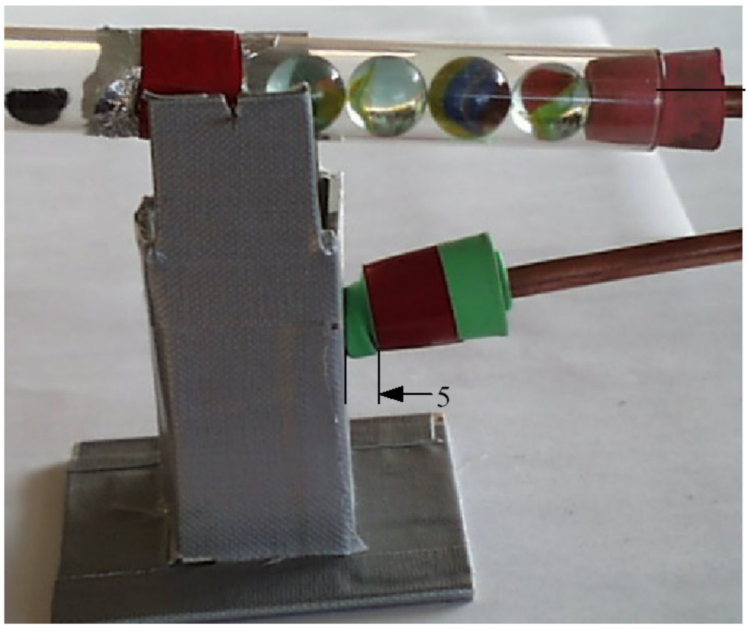


Fig. 4. The test-tube Stirling Engine.http://www.mech.canterbury.ac.nz/research/stirling/stirling.htm

The instructions, and a template for the base and forks are attached. Have fun, but be careful, it does get hot. Remember that if the marbles escape!

Student Activity 4

Describe how this simple Stirling engine works. Hint: the marbles act as the displacement piston.