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# The Thirsty Bird

A simple toy called the ' thirsty bird' (see cover) is an excellent way to introduce and illustrate to students how the differences of temperature and/or increase of entropy can be harnessed to produce useful work. First, some background. Mechanical work can be freely converted into heat. However, the French engineer Carnot[1] realised nearly two hundred years ago that there are limitations to the reverse process (extracting mechanical work from heat). Carnot's contribution was perfected by Clausius in Germany and Kelvin in Britain [2,3]. We now know that, if $T_c$ and $T_h$ are the temperatures of a cold and hot body, only a fraction $1-(T_c/T_h)$ of the heat removed from the hot body can appear as work. The remaining fraction $T_c/T_h$ of the energy is unavailable. Viewed in this light, much of the activity we see around us is possible because the sun has a higher temperature than the earth!

[1] N L S Carnot, *Reflexions sur la Puissance Motrice du feu et Sur Les Machines, Propres a Developper Cette Puissance.* Chez Bachelier Libraire, Paris, 1824 (see reference 1 for an english translation)

[2] R G E Clausius, *The Mechanical Theory of Heat*, Van Voorst Publishers, London, 1867.

[3] W Thomson (Lord Kelvin), *Philos. Mag.* 4, 8, 1854.

Consider a fuel heated power plant and assume as a rough simplification that the heat input is at 550K and that the heat is rejected at 310K. The ideal carnot efficiency would then be 0.436. However, one usually attains only about 75% of the ideal. Thus the final electrical power output is only about 30% of the heat input! Nuclear power plants operate at a lower boiler temperature of roughly 425K, which corresponds to a Carnot efficiency of about 27% and a realistic value of 20%. A still more extreme case is the proposed Ocean Thermal Energy Conversion (OTEC) process. This utilises the temperature difference between the warm (say 304K) water at the surface of the tropical oceans and the cold (say 272K) water deeper down. The Carnot efficiency is only 10% but the source is practically inexhaustible, and some experiments have been tried out.

With this background, students can be introduced to the toy which can swing to and fro about an axis mounted on the legs of the bird. The 'action' begins once the head of one bird is wetted with a few drops of water. Students can observe that the bird

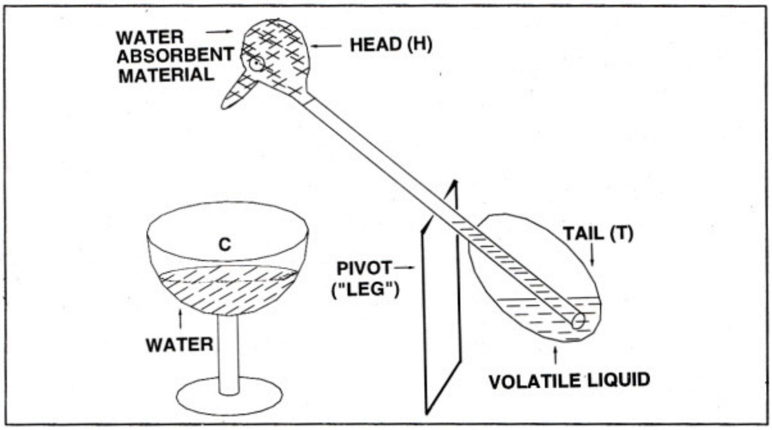


*Figure 1 Schematic diagram of the thirsty bird.*

starts to swing back and forth till it dips its beak in the water, after which the oscillations become smaller. After appearing to have its fill, the bird raises its head. But soon, the bird becomes 'thirsty' again and the cycle is repeated. In principle, these mechanical oscillations could be tapped to produce useful work. One can challenge the class to explain how the bird functions. It is surely not a perpetual motion machine! What is its source of energy and what is the sink? Could such devices be made practical?

## Description

The evaporation of water from the surface of the receptacle H (bird's head) where a water absorbent material has been attached produces cooling and thus contraction in volume of the air inside H (see *Figure 1*). The high vapour pressure liquid is forced through the tube from the tail, T, to the head, H. As the mass of H increases, that of T diminishes. The center of gravity rises towards H. The bird pivots (around the axis) and H tilts down towards the water cup, C. As H is lowered, the end of the tube dipping into the liquid contained in the receptacle T becomes exposed permitting pressure equalization and liquid flow back from H to T. The bird returns to a vertical position, and the cycle is repeated, as long as a temperature difference is maintained, which means until the source of water is consumed or the liquids in H and T arrive at the same temperature.

Shining a light from an electric bulb on T or increasing the temperature around T increases the swing speed.

## Explanation

Evaporation of water from the absorbent material on H keeps its temperature lower than the receptacle T. Heat energy flows with the molecules of high vapor pressure liquid from high (T) to low temperature (H acting as sink). This flow of heat is partly used to do some mechanical work. The temperature difference between T and H is only a few degrees K. For example 296K and 293K gives the efficiency of conversion of heat to work 3/296 = 1% which is very low and therefore this machine is not useful to derive work for practical purposes. Shining light on T will therefore increase the temperature difference between T and H. The number of swings per minute made by this machine can be measured by the students with and without an electric bulb near the receptacle T. Any increase in mechanical work thus obtained can roughly be attributed to a small increase in the efficiency of the machine due to the increased temperature difference created between the head and tail of the bird.

Ultimately, the mechanical work performed by the bird can be explained as a consequence of the evaporation of water from the surface of bird's head H which results in the increase[4] in entropy of water drawn from the cup. This change in entropy can be approximately described using an expression which is valid for isothermal expansion of ideal gases i.e., $S = nRlnV_2/V_1$ where $n$, $R$, $V_2$ and $V_1$ are the number of moles of water evaporated from the bird's head H, the gas constant, and the volumes of water to the vapor and liquid phases, respectively. The change in entropy can also be related as $S = q_{\mathrm{rev}}(T_h - T_c)/T_h T_c$ where $q_{\mathrm{rev}}$ is the heat flow from (T) to (H) and $T_h$ and $T_c$ are the temperatures at T and H respectively. The decrease in temperature at H due to evaporation of water from the surface of the bird's head results in an increase in the entropy of the water. This increase in entropy has partially been harnessed to do the mechanical work.

[4] Of course, in the case of an ideal heat engine, this increase at the sink is compensated by a corresponding decrease at the source.

## Suggested Reading


- **E Mendoza ea. *Reflections on the Motive Power of Fire and on Machines Fitted to Develop that Power.* Sadi Carnot and other papers on the Second Law of Thermo-dynamics E. Clapeyron and R Clausius. Dover Publications Inc. N.Y., 1960.**
- **J B Fenn. *Engines, Energy and Entropy.* W H Freeman and Co. NY, 1982.**
- **P W Atkins. *The Second Law.* Sci. American Book. NY, 1984.**
- **M L Lakhanpal. *Fundamentals of Thermodynamics.* Tata-McGraw Hill Pub. Co. New Delhi. Chapters 5 and 6, 1987.**
- **G W Castellan, V M Khanna, M H Kapoor and V P Sharma. *Physical Chemistry.* Narosa Publishing House. New Delhi. Chapters 8 and 9, 1995.**
- **M N Saha and B N Srivastava. *A Treatise on Heat.* S Chand. and Co.**