

Apparatus for Teaching Physics

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A Big Sunbird

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The drinking bird is a toy that is suitable for demonstrations in the classroom. Since it is able to produce work for long periods, this device resembles a *perpetuum mobile*, but of course it is not.¹ (With 30 cm³ of water, a drinking bird can operate for three to four days in summer.) The origin of its motion lies on a temperature gradient established between the lower part of the apparatus (the body) and its upper part (the head), by allowing water to evaporate off the head, which is kept wet.

It is indeed an interesting system, very useful to motivate high school and undergraduate students, and even the general public. The drinking bird combines classical mechanics, thermodynamics, and engineering, as happens with other thermal engines. Commercial birds are usually small, and therefore, not well suited for group demonstrations. Hence, we constructed a big drinking bird to be shown to large audiences. However, it turned out that a very low humidity was required for such a large model to work, and moreover, it moved very slowly.

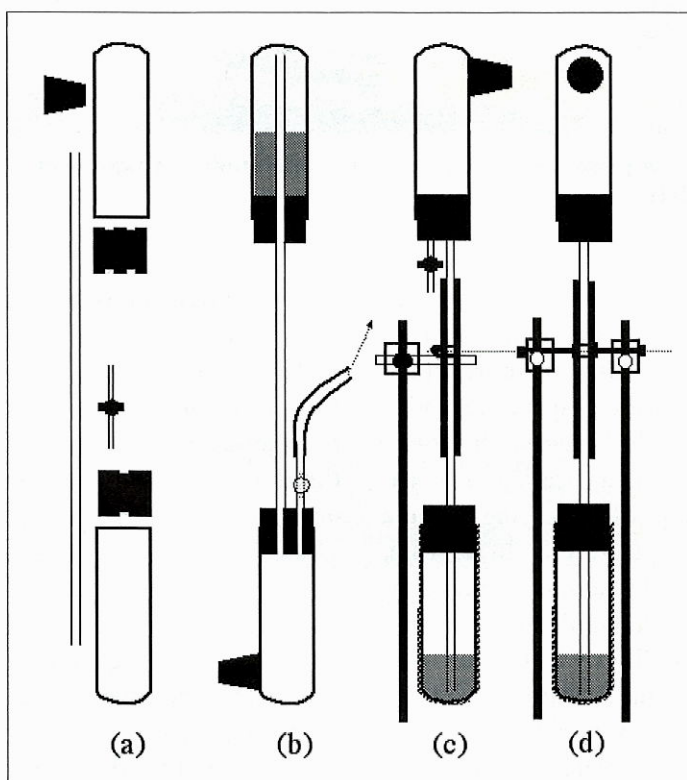


Fig. 1. Sunbird construction (not to scale). (a) Elements: two test tubes (length 0.167 m, external diameter 0.0493 m, mass 0.142 kg), two stoppers, one with two holes and the other with a single hole (each one with mass \approx 0.088 kg), a large tube (length 0.743 m, external diameter 0.0083 m), and one two-way stopcock (mass 0.049 kg). (b) The liquid is placed in the bird's body and inverted. The two-way stopcock is connected to a vacuum pump and locked afterwards. (c) A horizontal metallic rod is attached to the plastic protected tube and placed, free to oscillate, on glass rods (side view). The body is painted black. (d) A metallic rod, attached perpendicularly to the middle tube, lies on two small glass rods allowing for the bird's oscillation (front view).

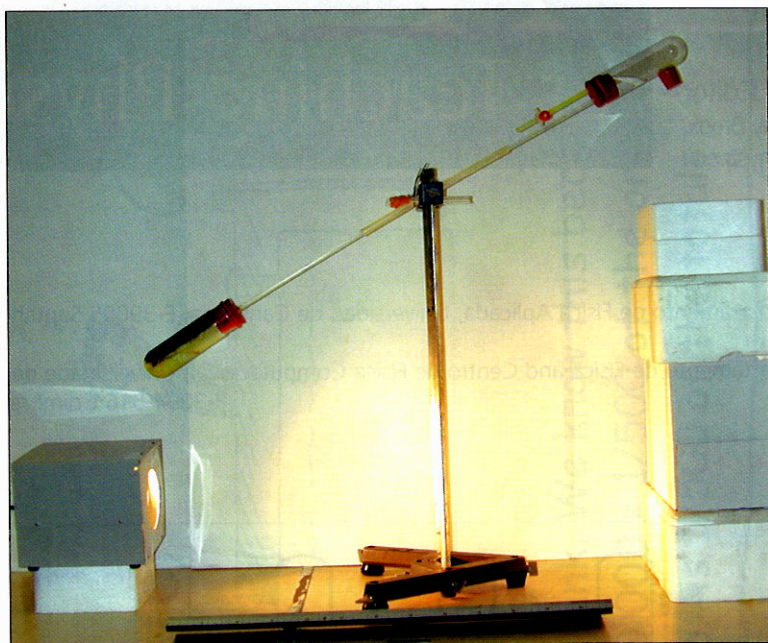


Fig. 2. A photo of our big sunbird in operation. The light comes from the left.

Nevertheless, instead of using the evaporation of water on the head as a cooling mechanism, there are other ways to induce a temperature gradient between the body and the head, namely by directly heating the body using a lamp, while keeping the head at room temperature.^{2,3} In this case, the bird's body should be painted in dull black and illuminated at short distances or directly by the Sun — hence the name sunbird — while the head remains in the shadow. The absorption of thermal radiation heats up the body, leading to a vapor pressure gradient inside the bird. This forces the internal liquid to rise up in the tube, making the bird perform a cycle similar to that of the drinking bird, but now the head is dry. The temperature gradient between body and head is easier to control in the sunbird, which operates in any external humidity conditions, so that the big sunbird does not suffer from the

above mentioned problems for the big drinking bird. This motivated us to design and construct the big sunbird (1 m high) for demonstrations to large audiences. The purpose of this note is to describe the details of our apparatus.

The big bird uses two glass test tubes, two rubber stoppers, one two-way stopcock, and a narrow glass tube as shown in Fig. 1(a). A vacuum pump is also necessary in the construction procedure. One test tube is the body and the other is the head. A small stopper, or something similar, is glued to the head to simulate a beak, inducing the bird to swing in a certain direction. The stopper for the head has two holes, one for the central tube and the other for the stopcock, which will be connected to the vacuum pump [Fig. 1(b)]. The stopper for the body has a single hole.

The narrow glass tube is intro-

duced in one of the upper stopper holes. The other extremity of the tube goes through the bottom stopper hole and almost touches the bottom of the test tube (the body) [Fig. 1(c)]. The two-way stopcock is inserted in the second hole of the upper stopper. The stoppers are fitted in the test tubes and the position of the narrow central tube is readjusted. The next step is to introduce the liquid inside the assembled bird. With the two-way stopcock in its open position, a long needle goes through it to introduce the liquid in the head, using a syringe. Next we turn the bird almost to a horizontal position, and with a gentle hand warming the head, the liquid is forced to move into the body.

With the liquid in the body, the bird is inverted and a vacuum pump is connected to the two-way stopcock while it is kept in its open position [Fig. 1(b)]. The vacuum pump is switched on, and after a few seconds, the liquid boils. The two-way stopcock is then closed and the pump removed. The body should be painted in dull black.

A small metallic rod is attached perpendicularly to the central tube. We used a metallic wire and surrounded, for the sake of protection, the middle of the glass tube with a plastic tube that fits well (friction against the plastic protection assures that the rod remains fixed) [Fig. 1(c)]. In a PHYWE V-shape base with multiple holes, two metallic bars are inserted. A small glass rod is attached to each bar and the bird is mounted in this structure with its transversal metallic rod lying over the glass rods. The bird must be free to oscillate with very small friction — see Fig. 1(d). To irradiate the body, it

is better to use a conic lamp (e.g., Philips Spotone PAR38 30° Flood 230 V, 120 W) rather than a spherical one.²

For a steady and fine operation of the sunbird some final adjustments are necessary. The fulcrum position must be chosen in order to assure that the bird tilts forward when almost all of the liquid is in the head. One may move the fulcrum position along the central tube or may introduce more liquid in the body. The bird's angle with the horizontal at dipping position must be conveniently chosen so that the liquid drains back well from the head to the body.

Diethyl ether, $C_2H_5OC_2H_5$, was used as the bird's internal liquid instead of the more common methylene chloride, CH_2Cl_2 . We used 60 cm^3 , though part evaporates during the pumping process. At room temperature, a temperature difference of 2.9°C is required to raise up diethyl ether to 1 m in a column (the normal boiling point is $T_b = 307.63\text{ K}$, the evaporation enthalpy is $\Delta h_v = 2668.80\text{ J mol}^{-1}$, and the density is $\rho = 0.714\text{ g/cm}^3$). A higher temperature difference, 6.3°C , is necessary to raise up methylene chloride to 1 m in a column ($T_b = 313.15\text{ K}$, $\Delta h_v = 28094.50\text{ J mol}^{-1}$, and $\rho = 1.336\text{ g/cm}^3$). Since these types of organic liquids may dissolve many rubber stoppers, chemical compatibility must be carefully checked.

Figure 2 shows our sunbird. When a conic light bulb is located 30 cm from the body, the period of the oscillation is 2.5–3 minutes. After a dip, the internal liquid column height remains above the fulcrum.

With this bird, many physics topics can be motivated and taught. We highlight the following: thermal radiation absorption (the bird's body may be painted in different colors or remain unpainted), square-law dependence of the intensity of thermal radiation (different lamps at different distances may be used), liquid-vapor equilibrium (suitability of different liquids on the basis of the Clausius-Clapeyron equation), and rotational dynamics, including the role of friction.¹

Acknowledgments

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Ed's Note: CAUTION! The described apparatus contains ether, which can cause unconsciousness or death if inhaled. As with any hazardous chemical, use proper precautions to make certain that there can be no leakage, spillage, skin contact, ingestion, or inhalation.

References

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