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Heat experiment with a microwave oven

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An experiment, suitable for an introductory laboratory course, is described in which a relatively common household item—the microwave oven—is used to do a heat experiment verifying the conservation of energy principle.

I. INTRODUCTION

The relatively common availability of kitchen microwave ovens offers the possibility of doing experiments[1] in which microwave radiation constitutes the energy source. The microwave oven recommends itself from at least two standpoints. First, the cost of a typical, simple oven is around $200, which compares favorably with the cost of equipment for the physics laboratory as found in the typical science-supply catalog. Second, the microwave oven is a relatively common household object, and hence—in the perception of the young student—is definitely part of the "real" world. Therefore, the utilization of such a familiar object in the relatively unfamiliar atmosphere of the introductory physics laboratory could be helpful from a pedagogical point of view.

The objective of the experiment is to verify the conservation of energy principle by showing that the temperature rise of a variable amount of water in a microwave oven is inversely proportional to the mass of the water, assuming that all other things (selected heating level, selected heating time, etc.) are kept constant.[2]

II. THEORY OF THE EXPERIMENT

The experiment is based on the familiar expression, $\Delta Q = mc\Delta T$, where ΔQ is the amount of heat energy absorbed by an object of mass m and specific heat capacity c, and ΔT is the resulting temperature rise of the object. In the experiment, ΔQ and c are constant, so that the expression may be rewritten as

$$\Delta T = k/m,$$

where k is a proportionality constant, and m is an an integral multiple of the amount of water in a typical kitchen cup. The experiment is taken to be a verification of the conservation of energy principle if the data are consistent with this expression.

The heat input into the water is held constant by simply operating the microwave oven at a fixed heating level for a fixed length of time for each value of m, as well as placing it always in the same place in the oven.

The basic experimental strategy is to assume: (1) that the distribution of the microwave field in the oven remains constant for the given configuration of the water sample; and (2) that the amount of microwave energy being absorbed by the water sample depends only on its surface area. The first condition appears to be met on the basis of the remarks in the preceding paragraph, and the second-condition is met by placing the water in a flat, pan-shaped container such that the height of the water is relatively small compared with the lateral dimensions; hence, for relatively small increments in the amount of water in the container, the surface area associated with this amount remains relatively constant compared with the change in the mass.

III. EXPERIMENTAL DETAILS

The oven[3] used to obtain the results reported here has a mechanical timer, uncalibrated heat control, but with LOW, DEFROST, and HIGH indicated on the heat-control knob, and a rotating food platform. In the experiment, the heat control was used in the DEFROST position. The calibration on the oven's timer was not used because it was considered to be unsuitable for accurate timing of the relatively short intervals (2 min) used in this experiment. Instead, a hand-held timer was used and the heating cycle was stopped at the end of 2 min. This particular timing interval was selected to render the effect of heat loss negligible, given that the thermal time constant of the system is estimated to be on the order of at least 10 min. The rotating food platform is considered to be a desirable feature from an experimental point of view inasmuch as the rotating sample would be exposed to the microwave field in a more uniform manner, averaged over several rotations of the platform. However, this feature is probably not necessary as long as the samples are always put into the same place in the oven.

The water was in a plastic food container (with tightly fitting lid) approximately 25 cm on each side and 8 cm high, and was added in increments of 1 cup (approximately 230 g per cup). This arrangement provided for the relatively small height-to-volume ratio required by the strategy of the experiment. The water was covered during the heating interval. Since the container does have some heat capacity, there is some temperature rise associated with it. Hence, at the beginning of each new run, the new water sample was stirred until the temperature reached equilibrium. An additional precaution consisted of placing a styrofoam mat (approximately 1 cm thick) on the rotating platform so that the plastic container would be more efficiently isolated from the platform (which becomes somewhat warm during the course of the experiment). Upon removal from the oven, the thermometer probe[4] was inserted into the container, which was then shaken appropriately a few times, after which the maximum temperature reading was recorded.

IV. RESULTS

Results are shown in Fig. 1 for a range of 1–4 cups (approximately 230 to 920 g). The expected inverse relationship between temperature change and mass of water being heated is readily demonstrated by the linear behavior of the data. These results are from just one run, indicating the quality of data that can be expected in the course of a typi-

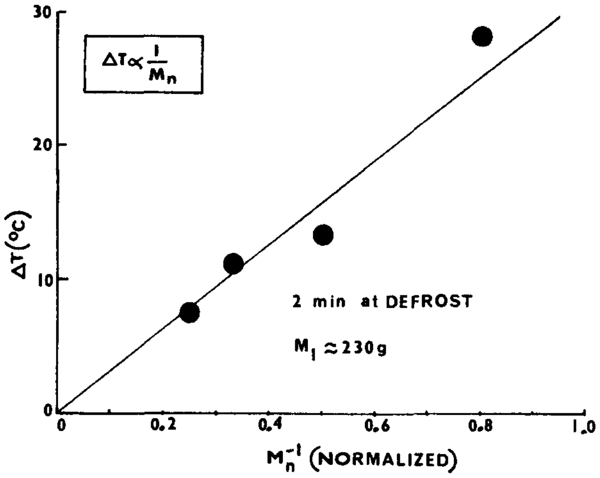

Fig. 1. Results from one run, showing the expected inverse relationship between temperature change ΔT and variable mass m_n. The index n runs from 1 to 4. A visually estimated best-fit line is drawn through the data.

cal 3-h laboratory session (in which there may not be enough time to obtain averaged values).

It is estimated that the container absorbs approximately 5% of the available energy for the case where the amount of water is 1 cup (230 g), but this is considered to be a negligible error in this experiment. Of course, for larger amounts of water, the effect associated with the container becomes even less significant.

V. CONCLUSION

An ordinary domestic microwave oven can be used to perform an experiment in which the temperature change of a variable amount of water is shown to be inversely proportional to the mass of the water, all other things held constant. The microwave oven affords the possibility of doing a relatively basic experiment—verifying the conservation of energy—utilizing a familiar (and "high-tech") object.

ACKNOWLEDGMENTS

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[1]Other experiments that could be based on the microwave oven include investigation of the relationship between skin depth and conductivity of water (a manuscript is in preparation on this experiment), measurement of relative absorption in various substances at microwave frequencies, etc.

[2]Some relevant background material on microwave heating and techniques are H. Puschner, *Heating With Microwaves* (Springer-Verlag, New York, 1966); *Physics Demonstration Experiments*, edited by H. F. Miners (Ronald, New York, 1970), Vol. II, pp. 1012–1031; J. R. Birchak, C. G. Gardner, J. E. Hipp, and J. M. Victor, Proc. IEEE **62**, 93 (1974); IEEE Spectrum **10**, 16 (1973); W. P. Lonc, Am. J. Phys. **48**, 685 (1980).

[3]Sanyo model NE-5670C rated at 500 W at full power.

[4]"Indoor/Outdoor" digital thermometer, commonly sold at hardware stores, etc., for approximately $20. The "Outdoor" probe (containing a thermistor) has a mass of approximately 2 g.

Dynamic impedance matching with a lever

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Multiple elastic collisions are analyzed that occur between an incident mass M_1, a target mass M_2, and a single intermediating hinged lever of moment of inertia I that bounces back and forth between the two masses, transferring angular momentum and energy with each double collision until, if I is chosen correctly, 100% of the energy has been transferred from M_1 to M_2 in N double collisions, where $N = 1$, or 2, or 3, or ... . The model was inspired by the mechanical transformer, designed and built by Ansbacher, that employs two nearly massless levers as intermediaries so as to achieve nearly complete energy transfer between two masses on an air track.

I. INTRODUCTION

In his note, "Impedance Matching on the Air Track," Ansbacher[1] describes an ingenious device that he designed and built consisting of a mechanical "transformer" that accomplishes nearly complete energy transfer from an incident mass M_1 to a target mass M_2 that is initially at rest.[2] The Ansbacher transformer uses two hinged levers as impedance-matching intermediaries. Mass M_1 strikes lever #1 at normal incidence causing lever #1 to strike lever #2, which then strikes mass M_2. Ansbacher derives the design condition for complete energy transfer by assuming the familiar "law of levers." At first this puzzled me. When we first learn the law of levers as freshmen we learn that the net torque on a lever must be zero if the lever is not to undergo angular acceleration, as for static equilibrium (or

