Additional Information

Microwave and Chocolate Selection

The most important experimental factors to consider are the type of chocolate used and the size of the microwave oven. Standard "foot-long" chocolate bars (usually 29 cm) work best because they provide some room for error and are readily available at grocery stores. Refrigerated pure dark chocolate bars without walnuts, hazelnuts or raisins are ideal. The fat in milk chocolate has a melting point which is lower than the cocoa butter in dark chocolate, and consequently, when milk chocolate is heated in a microwave oven, the heat at the antinodes spreads quickly through the bar by convection, melting the chocolate before the antinode pattern becomes apparent. Cleaner results are obtained with dark chocolate because the higher melting point allows more power to be channeled into the antinodes before the heat is able to dissipate through the chocolate. Refrigeration of the chocolate prior to experiment also helps to delay melting by convection because the amount of heat which must be transmitted from the antinodes through the bar is increased.

As previously mentioned, the size of the microwave is very important and is somewhat dependent upon the size of the chocolate bars which are used. A minimum clearance of 2-3 cm, on all sides, between the chocolate bars and the walls of the cooking chamber, is required. For instance, if standard "foot-long" bars are employed, a cooking chamber with a width (defined as the dimension parallel to the door) of 33-35 cm is recommended. If a microwave oven of this size is not available, squares may be broken off of the bars in order to give the required minimum clearance. A larger microwave works best since it can accommodate more chocolate, increasing the number of melted hotspots. The magnetrons in conventional microwaves emit wavelengths between 11.8 cm and 12.3 cm. The precision of the measured wavelength is limited by the size of the antinodes, which are typically at least 2 cm in diameter. In order to help minimize error, a microwave oven with a minimum cooking chamber width of 28-30 cm is a must.

Useful Conversions

To estimate the speed of light in metres per second (m/s), SI units must be used: hertz (Hz) for frequency and metres (m) for wavelength. The following conversions will assist in the calculations:

$$1\ \text{GHz} = 10^9\ \text{Hz}$$
$$1\ \text{MHz} = 10^6\ \text{Hz}$$
$$1\ \text{cm} = 0.01\ \text{m}$$

The speed of light is equal to the wavelength (λ) multiplied by the frequency (f) of an electromagnetic wave (microwaves and visible light are both examples of electromagnetic waves). The speed of light in a vacuum is a constant value and is denoted as *c*. Electromagnetic waves propagate through free space at the speed of light.

'c' is for Chocolate - Additional Information

Sample Calculation

A chocolate bar placed in a 2.45 GHz microwave for 90 seconds melts in two places, spaced approximately 12 cm apart. The velocity of the electromagnetic waves can be estimated using the following equation:

$$\lambda f = v$$

where, λ is the wavelength of the microwaves (12 cm), f is the frequency of the microwaves (2.45 GHz) and v is the speed of the waves. The calculation is as follows:

$$\lambda f = (2.45 \times 10^{9})(0.12 \text{ m}) = 2.94 \times 10^{8} \text{ m/s} = v$$

The constant in this equation is the operating frequency of the microwave (2.45×10^9 Hz). By plugging in the measured wavelength, the speed of light in a vacuum is obtained (299 792 458 m/s). In this case, the calculated speed of light value deviates from the true value by only 1.9%. This calculation provides a check on the accuracy of the measured wavelength, where good agreement between the experimentally determined speed of light and the known constant indicates that the measurement of 12 cm was in fact quite accurate.

To further complicate the analysis, it is possible that the distance between some of the areas of melted chocolate be greater or less than 12 cm (e.g., 6 cm, 18 cm, or even 24 cm apart). This happens when the original standing wave generated by the microwave (the solid red line in **Figure 1)** is reflected back upon itself (the dashed blue line in **Figure 1**). The reflected wave has antinodes which are located between the antinodes of the original standing wave, resulting in melting which occurs every 6 cm instead of every 12 cm. The original standing wave has more energy than the reflected wave, and therefore its antinodes (located 12 cm apart) may be distinguished by their increased melting.

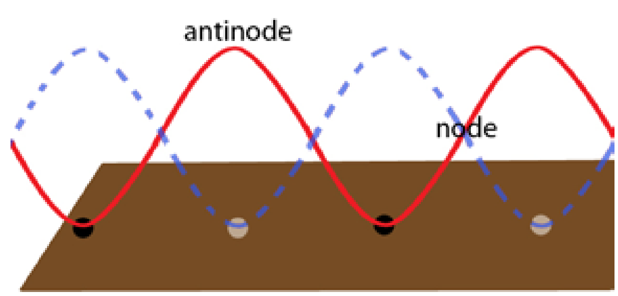

Figure 1