

Teachers' Guide:

While we have done our best to guide you through every step of the experiment, we suggest you try to follow the guide by yourself to see which points your students might need clarification on, as well to get a sense of which parts of the experiment are more difficult.

For younger students, you may wish to simply skip question 1, and answer questions 2 with respect to indent size.

A bag of about a 100 marbles costs less than a dollar, but watch out for varying marbles sizes. One bag may have different sized marbles – in preparing this lab, we chose the large marbles



(“shooters” – 22 mm diameter) because they were easier to attach to a stack of pennies. Also, try to get marbles with smooth surfaces.

Answers to Questions:

4. It is important that the indenter be harder than the material being tested because you don't want any deformation to occur in the indenter. Imagine trying to indent the chocolate with a cotton ball - the cotton ball would deform before the chocolate, and the indent size, if there is one at all, would not be an accurate measurement of the way the chocolate responded to the force applied on it. It is also important because the formula is configured for a sphere – if there was significant deformation in the indenter, this formula may need to be adjusted.
5. Different types of chocolate have differing hardness because their properties are inherently different. White, milk, and dark chocolate will contain different ratios of milk to cocoa ratio. Nuts are generally much harder than chocolates, so a bar like Hershey's Mr. Goodbar are likely to be much harder to indent than pure milk chocolate.
- 6-8. Ideally speaking, a material only has one value of hardness at a certain temperature and composition. Variables like load, drop height (which really just changes the load again) and marble size are all accounted for in the formula for hardness, and so changing them may lead to smaller or larger indents, but the value of the hardness should remain constant.

9. Generally, materials get harder and more brittle in lower temperatures, and softer and more ductile under heat. A partially melted chocolate bar might not require much of a load to deform, and you can qualitatively state that it is less hard; on the other hand, a frozen bar would require a larger load, and might in fact crack or shatter before it deforms significantly.
10. It's all about control. By slowly easing the indenter into the material, scientists can track variables such as load and displacement more accurately. The experiment outlined in this lab takes just a single measurement of the hardness, but by slowly pressing the indenter into the material, one could sample data several (hundreds or thousands of) times and measure hardness more accurately. This procedure also allows tracking of how the material reacts when you pull out the indenter from the material, something which is not possible using the guidelines in this lab.
11. Generally, the harder the material, the higher its strength. When students graph hardness VS strength, this relationship will become evident. Chocolates further on the X scale, should be higher up on the Y scale, and vice versa.

Additional Aspects to consider if your lab is equipped with:

If you have a fridge / microwave available to you:

- Try altering the temperature of the chocolate to see the effects discussed in question 8

If you have large weights available (such as bricks):

- Try conducting the experiment more like modern hardness testers. Set the marble on the surface of the chocolate and place a large weight on it (slowly) until the weight rests solely on the marble (balancing might be an issue). You can now directly calculate the force applied to the chocolate, as it will simply be the mass of the weight + marble multiplied by the gravity constant (9.81 m/s^2).

Alternative or Extra experiments if you have leftover time or chocolate:

Try changing the height of the drop, the weight of the indenter, or the shape of the indenter (different size marbles, or use pencils) to see effects discussed in question 6.

Try the experiments with different materials. Any material which can deform under the weight of your thumb is appropriate for this lab. Some easily available materials to test would be wax (i.e. candles), silly putty, clay etc.