Students' Understanding of Thermal Equilibrium

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The two pivotal ideas in thermodynamics are heat and temperature. These however are interdependent and their definition draws upon a third concept, namely thermal equilibrium. We report our work on students' understanding of thermal equilibrium. We found that many students do not understand concepts such as thermodynamic variable and adiabaticity necessary for discussing thermal equilibrium. Also, they establish a strong dependence of thermal equilibrium on the size and the material of the objects under study.

Keywords: Thermal equilibrium, Thermodynamic variable, Adiabatic, Diathermic, Students conceptions

Introduction

The fact that the students have their own framework of understanding of how things work prior to receiving formal education is well accepted by the physics education researchers' community. Students enter the classroom with their own understanding about the topics that they learn. This has been well established by many researchers. Most of these misconception studies cover areas like mechanics, optics, electricity and magnetism (Pfundt & Duit, 1994). Comparatively less attention has been paid towards heat and thermodynamics. While exploring children's and adults' views about thermal equilibrium, it was observed that the scientific model possessed is not simply acquired from one's accumulated experience of thermal phenomenon but must instead be explicitly taught. Some extensive interviews also revealed that many students find reasoning about activities regarding thermal phenomena extremely difficult. This was found not due to a lack of hands-on-experience of heating task and events, but rather to an inability to interpret these phenomena using the language and concepts of a coherent scientific theory of heat and heat transfer (Arnold & Millar, 1992). The two pivotal ideas in thermodynamics, temperature and heat are often regarded as synonymous (Tiberghien, 1985). Erickson quotes a typical response in which temperature seems to be either "a measurement of heat" or "the effect of heat" (Erickson, 1985). It was also found that the children do not take into account all the parts of an interacting thermal system often neglecting the surroundings in the explanation (Tiberghien, 1985). Most of these studies in thermodynamics have been at the pre-college level (Loverude, Kautz, & Heron, 2002). Some studies have been focused at engineering students, but much less work has been done at the undergraduate science level. This reason and the inherent complexity of the subject inspired us to take up an exploratory study of the misconceptions of undergraduate students in this subject.

Preliminary studies conducted by us, gave us some idea of students' understanding about concepts like pressure, heat and temperature, about heat transfer mechanisms and about elementary kinetic theory (Pathare & Pradhan, 2005a, 2005b).

The pivotal concepts in elementary thermodynamics are heat and temperature and the definitions of these draw upon the concept of thermal equilibrium. We therefore decided to investigate students' ideas about thermal equilibrium. We report on this investigation.

Methodology

Students in our sample were from colleges in the metropolitan cities of Mumbai and Bangalore. Our sample consisted of 291 college students, 251 from Bangalore and 40 from Mumbai. These students are introduced to heat and thermodynamics in the last two years (Class XI and XII) of their school. A more detailed encounter with the subject occurs in the first and second year of their undergraduate studies which extends for three years after class XII. Even before class XI students have had some acquaintance with ideas of heat and thermodynamics, both through studies at school and through daily life experiences.

A set of 14 multiple choice questions was developed covering the topic of thermal equilibrium. A careful scrutiny of the questions was carried out to check the questionnaire for language, accuracy and distracters. Further it was given to 23 students in a pilot study. We found that some questions needed substantial modifications, while three questions were dropped for reasons such as obviousness and ambiguity. We finalised the questionnaire consisting of 11 questions which was administered to the students in the sample for a duration of 30 minutes.

For each alternative of each item we worked out the percentage of students marking that alternative as the correct option. Typically if there are two alternatives in an item, then there is a

50% probability of choosing randomly each alternative as the correct option and for four alternatives this probability is 25%. For the given sample size, we calculated the standard error in these percentages and from there, the 95% confidence interval for each percentage (50% ± 6% and 25% ± 5%). An incorrect answer with probability more than the higher limit of the confidence interval would be a candidate for misconception. If such an answer was coupled with a correct alternative having probability less than the lower limit of the confidence interval, the likelihood that the answer indicated a misconception was even greater. This was further probed through a qualitative study of the students' choice of alternatives and through detailed interviews of the students. Fifteen students were interviewed.

Analysis

The results reported in this paper are based on the analysis of students' responses to the questionnaire supported by the analysis of the interview sessions.

Understanding thermodynamic variables and thermodynamic equilibrium

The behaviour of a system and its interaction with its surroundings is studied through a macroscopic point of view (as in thermodynamics) or a microscopic point of view (as in statistical thermodynamics). The macroscopic point of view deals with variables of a system at approximately the human scale or larger whereas the microscopic point of view deals with variables of a system at approximately the molecular scale or smaller. Thermodynamics deals with macroscopic properties or characteristics of a system (Dittman & Zemansky, 1997).

Students were given a situation in which a cylinder (with a gas enclosed in it) fitted with a movable piston was kept on a moving platform. They were asked to identify a thermodynamic variable out of the four alternatives given (see Q.1 from appendix). Half (50%) of them regarded the velocity of any gas molecule to be a thermodynamic variable. In elementary kinetic theory, students learn that the average velocity of the molecule is related to the temperature of the system which is a thermodynamic variable. Hence they seem to think velocity of a gas molecule is a thermodynamic variable. They ignore the subtle distinction between the velocity of a molecule and average velocity per molecule. Some students considered even the position of the center of mass of the system as thermodynamic variable.

Student 1: ... *since the piston is moving, the center of mass of the system will change…*

Here, the student seems to relate the center of mass of the system with the movement of the piston which corresponds to a change in the state of the system. A variable connected with the change in the state of the system, for the student, is a thermodynamic variable.

Another question asked the students explicitly what a thermodynamic variable meant to them. It was rather surprising to note that a good 36% of students said that any microscopic quantity describing the system is a thermodynamic variable. The correct answer that thermodynamics variable is a macroscopic quantity having a bearing on the internal state of the system, was given only by 21% of students which might have even come through a random choice.

Students seem to detect equilibrium by the presence of the term "no change in time". They are not critical about what exactly is not changing in time and what may be changing in time in thermodynamic equilibrium as seen from Question 2 in the appendix.

Confusion between adiabatic and diathermic

In thermodynamics one uses the terms 'adiabatic and diathermic walls'. An adiabatic wall does not allow the exchange of heat through it. The diathermic wall is exactly opposite. If two systems are separated by an adiabatic wall then the two systems may be in equilibrium independent of each other i.e. the equilibrium values of thermodynamic variables of one system are completely unrelated to those of the other system. If two systems are brought in contact through a diathermic wall, then the values of the thermodynamic variables of the two systems are no longer independent, but the values of thermodynamic variables of one system impose a restriction on the values of the thermodynamic variables that the other system can have. Question 3 shows the students lack of understanding of the concepts of adiabatic and diathermic.

The students were also given a list of materials which they were supposed to categorise as suitable for adiabatic and diathermic wall. They were told, for facilitating clear choices, that the materials considered were of equal thickness. The materials given were plastic, glass, brass, paper, rubber, concrete, diamond, aluminum, gold and Teflon. Of these brass, diamond, aluminum, are suitable as diathermic and the others are suitable as adiabatic. This categorisation activity brought to our notice the confusion that students face. The key to this question is to consider the thermal conductivities of the materials. Students on the other hand gave different reasoning, based on their everyday experience to determine which material is adiabatic and which is diathermic. Many students confused glass, paper, concrete as diathermic.

Student 2: ... *coffee feels hot through glass…*

Student 3: ... *paper burns…*

Student 4: ... *in summer concrete roof becomes hot… (which) makes us feel hot…*

Diamond is a bad electrical conductor but a good thermal conductor. Students were unaware of the behaviour of diamond and simply choose an alternative at random.

Object size and thermal equilibrium

Students were given a situation in which two wooden cubes of different sizes (27 cm^3 and 125 cm^3 initially at room temperature), were kept in a hot air constant temperature enclosure (maintained at 70°C) for a few hours. They were asked to comment on the temperature of each cube after the cubes were kept in the hot enclosure for a sufficiently long time. A good percentage of them (43%) agree that both the cubes attain a steady temperature but they feel that the temperature attained by each cube will be different. A sizeable number of students feel that the smaller cube will attain a greater temperature than the bigger cube. The interviews of the students confirm this.

Student 5: ... *smaller cube will acquire greater temperature as it will require less heat to do so…*

Material of the object and thermal equilibrium

Students were given a situation similar to that given above with two cubes with equal sizes but different materials. The cubes were initially at room temperature and then transferred to a hot enclosure at 70°C and kept there for a sufficiently long time. Majority of students (64%) replied that the temperature of the copper cube will be greater than the temperature of wooden cube as the thermal conductivity of copper is greater than that of wood. On the other hand a very small minority (10%) opt for the correct alternative that both the cubes will attain the temperature as that of the enclosure. Since both these alternatives lie well outside the confidence interval for random choice, we believe that we have come across a strong misconception. The students seem to feel that since the rate of increase of temperature of copper will be higher than that of wood, temperature attained by it will also be higher.

Effective temperature of the mixture

For a question on the final temperature of mixture of two identical samples of liquid initially at different temperatures (34°C and 96°C), 38% of students gave the correct answer (65°C). Surprisingly, almost an equal number of students (32%) gave the difference of two initial temperatures (62°C) as the correct answer.

Another question was also on mixture of two liquids at different initial temperatures but the difference was that the experiment was carried out on a platform moving with velocity *v*. In this case 40% of the students felt that the temperature of the mixture could not be determined as it would depend on the velocity of the platform. Only about 12% gave the correct answer of 60°C. Since, here the correct alternative is given by less number of students lower than the minimum of the confidence interval for random choice, we have a case of misconception. Students do not realise that the platform moving with a uniform velocity will not alter the internal state of the system in any manner.

Conclusion

While students do have certain deep rooted alternative conceptions, they do seem to have many non-conceptions. For example, many seem to be ignorant of the distinction between macroscopic and microscopic, between adiabatic and diathermic, between a macroscopic variable and a thermodynamic variable. Students take into account all parts of an interacting thermal system, often neglecting the surroundings in their explanation. They relate their daily experiences rather than scientific information to categorise the materials as suitable for adiabatic and diathermic walls. Students do not believe that objects kept in a constant temperature enclosure for a sufficiently long time will tend towards thermal equilibrium and reach the same temperature as the enclosure, but rather relate it to the size and material of the object under consideration. In view of these and other similar findings, we are now developing a teaching approach which will address the alternative conception and difficulties that we have come across. We believe that actual experience through activities, rather than theoretical reasoning, will enable the students to realise their own alternative conceptions (Pathare & Lahane, 2009). Hence our teaching approach will be based on activities.

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Appendix

Sample questions from the questionnaire:

Q.1 Consider a gas enclosed in a cylinder fitted with a movable piston. The cylinder is kept on a platform which is moving. Example of a thermodynamic variable for the gas in the cylinder taken as a system is

a) the velocity of the cylinder

b) the position of the center of mass of the system

c) the velocity of any molecule of the gas enclosed

d) none of the above

Q.2 If a system is in a state of thermodynamic equilibrium,

a) the macroscopic variables of the system and the surrounding do not change in time; the microscopic variables of the system and the surrounding may be changing in time.

b) both macroscopic as well as microscopic variables of the system and the surrounding do not change in time.

c) the microscopic variables of the system and surrounding do not change in time, the macroscopic variables may be changing in time.

d) both macroscopic and microscopic variables of the system may be changing in time but those of the surrounding do not change in time.

Q.3 Two systems A and B are characterized by definite thermodynamic variables X_1, Y_1, and X_2, Y_2 respectively. These two systems are separated by a wall. They are not in equilibrium with each other at the instant when observed. After a while,

a) X_1, Y_1, and X_2, Y_2 will remain the same irrespective of whether the wall is adiabatic or diathermic.

b) X_1, Y_1, and X_2, Y_2 will change irrespective of whether the wall is adiabatic or diathermic.

c) X_1, Y_1, and X_2, Y_2 will change if the wall is diathermic.

d) X_1, Y_1, and X_2, Y_2 will remain the same if the wall is diathermic.