Diagnosing the nature of energy - the case of kinetic energy

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Abstract. A questionnaire was designed to diagnose the awareness regarding aspects of kinetic energy that are rarely addressed in the teaching context: (1) Its relativistic nature and (2) its positive value for a system of mutually moving objects regardless any suitable choice of an inertial reference frame. Failure to recognize these aspects may lead to contradiction with the energy conservation law and thus may be regarded as misconceptions. Here we studied science teachers' knowledge with this respect based on specially designed diagnostic questions. The findings indicate that teachers exhibit difficulties in reconciling the contradiction mentioned above.

1 Introduction

Many students were reported to fail, both in qualitative and quantitative reasoning, in recognizing the implications of a particular choice of system when addressing situations involving gravitational or elastic potential energy. It was claimed that choosing the system of interest should be emphasized since inconsistencies in considering systems can have serious implications.[1] However, it was not pointed out that such a choice is more than a matter of interest but involves a fundamental principle, related to the nature of energy.

Among the various characterizing aspects of kinetic energy (KE) one is often not addressed in the context of science education: that the zeroth point of a system's KE cannot be absolutely determined (Zero point aspect). This aspect is the result of two features of the KE: (1) its relativistic nature, i.e. that the KE of a single object is frame of reference dependent, and (2) that the total KE of a system of mutually moving objects, cannot be reduced to zero by any suitable choice of the inertial reference frame. Failure to recognize each of these aspects may lead to contradiction with the energy conservation law and thus may be regarded as misconceptions.

Consider, for example, the following scenarios: (I) A block on a frictionless floor within a stationary train (relative to the trails) is propelled by a spring into 10 m/sec speed. (II) Similar to case (I) except that the train initially moves with speed of 10 m/sec in the same direction as the block. Omitting the change in the train's energy in the process leads to contradiction with the work-energy theorem and thus with the law of energy conservation. This contradiction is not resolved by choosing neither the block nor the block and the spring as the system. Hence, choosing the system is not merely a question of interest as is often claimed [1], but a matter of a fundamental principle: in performing energy considerations one has to take into account all the interacting objects as a system. In fact, the correct representation of the energy conservation law would be:

$$-\Delta U_{spring} = W_{spring} = \Delta E_{K(block)} + \Delta E_{K(train)} \qquad (1)$$

Many energy diagnostic questions (e.g. [1] & [2]) are not clear regarding the relativistic nature of KE and its implications. Here we report on findings from a research that employs questions specially designed for revealing difficulties in this respect.

2 The research - Methodology, findings and preliminary inferences

The research questions: We addressed here the questions: (a) Do science teachers show awareness regarding the possible contradiction between aspects (1) and (2) of the KE nature and the energy conservation law? and (b) How do they reconcile it?

We administered specially designed diagnostic questions to science teachers with respect to this possible contradiction (we report here on an analysis of 52 addressees, 21 of them are high school physics teachers). These questions asked to consider situations from different inertial frames of reference which involve motions under (a) the force of gravity and (b) under the force of a spring. If the changes in KE of all the interacting objects are not considered (a proper systemic view) such situations could lead to contradiction with the law of energy conservation.

Findings: We found that although all of the teachers regarded speed itself as relative, most of them (93%) regarded KE as absolute, stating that it is because of the speed square in the KE formula. This led them to regard a change in KE as frame of reference dependent (i.e. different changes in KE for the same change in speed). Many (65%) related zero KE to a system of mutually moving objects when choosing the frame of reference of the "moving" object. Most interestingly, many of those who consistently adhered to the energy conservation law ignored the relative nature of KE and vice versa: those who accepted this last feature of KE violated energy conservation in their answers. The responses indicate that choosing the spring-block (or a like) as a system, but relating a change in the KE only to the block, ended up with a violation of the energy conservation law.

3 Conclusion

Our findings indicate that the KE zero point aspect, with its two features (1) & (2), posed a great challenge for our sample. Moreover, choosing the spring & the block (or similar) as a system did not help the teachers to reconcile the apparent relativity-energy conservation contradiction since they never referred to the other object (the "wall") which undergoes a change in KE. We therefore recommend (as advocated in [3]) an instruction based on (A) equation (1), which emphasizes the change in energy during a process as the fundamental scientific concept and on (B) emphasizing the proper choice of a system in accord with the interacting objects.

4 References

[1] Lindsey, B. A., Heron, P. R., & Shaffer, P. S. (2012). Student understanding of energy: Difficulties related to systems. *American Journal of Physics, 80*(2), 154-163. doi:10.1119/1.366066

[2] Lin Ding, L., Chabay, R. & Sherwood, B. (2013). How do students in an innovative principle-based mechanics course understand energy concepts? *JRST, 50(**6**),* 722–747.

[3] Lehavi Y., Eylon BS. (2018). Integrating Science Education Research and History and Philosophy of Science in Developing an Energy Curriculum. In: Matthews M. (eds) *History, Philosophy and Science Teaching. Science: Philosophy, History and Education.* Springer, Cham.