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Learning mechanics with toys

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1. Toys as familiar objects of everyday life

One severe problem of teaching physics, especially mechanics, is the difficulty in stimulating pupils to investigate and understand objects of everyday life from a physical standpoint, i.e. differently than they are accustumed to doing. Since these objects do not carry, in any simple way, a physical aspect in themselves, the physical consideration of them largely requires one "to describe the world in a way that we do not experience it" [1].

This problem does not fully appear if physics is applied to the artificial world of physical apparatus and materials which have only been prepared to demonstrate one or at best several physical principles. Normally, this is the case in German schools.

Since this world of apparatus scarcely has any connections with the everyday world of the pupils one cannot expect students were able to apply physical principles to it. However, this should be one of the main objectives of physical education, unless physics is to be simply an end in itself.

To ignore the specific difference between the scientific and the everyday world is a mistake. Indeed, pupils should at least learn some examples of

- how the physical consideration of a certain object can be motivated,
- which advantages and disadvantages are associated with it, and they should come to know
- some typical physical models.

  Not every object is suited for this task. It must

- have a nonphysical purpose to be representative of an object from the everyday world,
- be of a sufficiently simple construction, and
- be interesting enough to stimulate the pupils to investigations. Many familiar toys may be taken as representatives of such objects.

2. Toys have an effect an the senses

Toys are made for playing: they should be fun to deal with.
The affective and motorial relations to toys, developed by playing with them, stimulate and support the experimental and intellectual treatment of toys. Toys reach the senses. Therefore, handling toys in physics lessons may help accentuate the "sensory content" of physical phenomena which threatens to be spoiled within the widespread blackboard and demonstration physics [2].

3. Application of toys in physics courses

The application of toys in physics is, above all, a methodological problem which, in general, can only be solved with actual lessons. Therefore, the following proposals are given as rough clues:

- If possible, artificial apparatus should be substituted by toys. For instance, many qualitative physical connections may be derived with the help of toys.
- Even if exact measurements are intended, toys may play an important role in stating and working out the corresponding problem.
- Sometimes, toys can be used to illustrate abstract physical statements and laws and to help get a clear intuition of such statements and laws.
- Since some toys (not necessarily complex ones) refer to several physical-topics, they are usually well-qualified to be treated in a physical project [e.g. see 3].

4. Examples of mechanical toys

We can only give here a limited survey of mechanical toys. We try to be representative both in the spirit of the preceding considerations and with respect to physical aspects covered by this selection. For a more detailed and deeper understanding or reference to further aspects, not treated here, we give a corresponding reading list.

4.1 Colliding balls

The "bouncing ball" can be regarded as a paradigma of a multitude of mechanical phenomena, the study of which may provide for a number of important physical notions and principles (e. g. energy, momentum, conservation of energy and momentum, law of reflection etc.).

<u>Bouncing balls</u>: The coefficient of restitution e may

be determined for balls of different sizes, materials et. [4]. For instance the height of a ball after the n-the collision or the height of a small ball "riding an the back" of a big ball when reflected from the floor [5], can be calculated by means of γ.

- Ball chains: The nearly instantaneous transport of momentum through a chain of equal sized steel balls is the surprising effect of the so called "Newton's cradle" [5,6]. In addition to a discussion of this phenomenon, it is interesting to investigate the deviating effects which appear, e.g. when different sized balls or balls of another material (e.g. superballs) are regarded [7,8].

- Billiard balls: Colliding billiard balls represent an important paradigma of all kinds of collision processes in classical physics [9]. In addition to an investigation of typical collision phenomena [10] the cooperation between sliding and rolling motion can be discussed. The limits of the billiard ball paradigma may be evaluated by considering small perturbations during a number of successive collisions [11].

- Superballs: These highly elastic balls nearly satisfy the no-slip condition of reflection, leading to a number of impressive effects (e. g. reversion of the direction of motion after two reflections) [12, 13].

4.2 Rolling wheels and spinning tops

The effects of rolling and spinning, present, at least to some extent, in nearly every ball game, are somehow surprising and unexpected. The conceptualisation of this effects leads to a number of notions and principles (e.g. angular momentum, torque, moment of inertia, rotational energy etc.) which may be developed analogous to the corresponding notions of translational motion.

- Rolling wheels: A survey of some simple and typical rotational effects may be obtained by investigating wheels or cylinders of different mass, size, and form (hollow or solid) rolling down inclined plains.

- Yoyos: Some concepts and rules worked out with rolling wheels may be applied, at least. in principle, to understand this well known toy [14,15].

- Tops: There are many different kinds of tops, each being typical for a particular phenomenon. A detailed description of too motion is difficult. But simple qualitative or semi quantitative considerations of stationary states provide a general understanding of the most important features [16]. Peg tops and whip tops Show behaviour which is in some respects representative of fricionless motion. The phenomena of the space stable axis, precession and nutation, i.e. the typical unexpected responses to disturbances, may be studied by means of them. Besides other special effects the gyroscope shows the influence of friction leading to a steady increase of the precession angle. This effect is continued in the case of the tippe-top, which reverses and finally revolves stably an its stem, although thereby the centre of gravity is lifted and the angular momentum is changed [17,18,19]. Finally, some other top-like objects, the diabolo, the boomerang, the discus and similar toys can only be mentioned here.

4.3 Aerodynamic toys

In so far as the interaction of moving or spinning objects with the surrounding air becomes important, aerodynamic effects have to be taken into account.

- Flying balls: One would expect that with increasing speeds of a flying ball the range of the ball decreases due to aerodynamic drag forces [20]. Surprisingly, this is not in general true. At very high speeds (i. e. at Reynold numbers above 10^5) the drag force drops sharply giving rise to greater ranges (e.g. golf balls) [21].

  If a flying ball is spinning there is another important effect, a force perpendicular to the flight direction (Magnus effect) giving rise to rather surprising distortions of the normal projectile parabola (e.g. top spin and slice of tennis balls) [21].

- Boomerang: The behaviour of boomerangs, discus', and similar toys cannot be fully understood an the basis of top dynamics. The interaction with the air (e. g. Magnus effect) has to be taken into account [22,23].

- Paper airplanes and kites are aerodynamic toys in the true sense [24]. In particular, paper glider can be easily constructed, and can be experimentally investigated by varying the construction according to plan [25]. A special paper helicopter [26] may be taken as a model to understand the well behaved rotational flight of winged seeds [27].

4.4 Oscillating toys

Oscillation is one of the most important concepts within all areas of physical reasoning. The original paradigma of oscillatory behaviour is the simple pendulum, which can be understood as the linear approximation of all kinds of oscillatory motion. Although in school physics, this approximation of harmonic motion is taken to be synonymous with oscillation or vibration, most oscillating toys work by self-induced, hence by non-linear oscillation: In this phenomenon a force causes a vibration and the vibration controls the force. Apart from the toys considered here, practically all musical instruments produce sounds by self-induced vibrations; e.g. the flute, Organ, clarinet, cornet. (The piano and other musical Instruments in which the vibrations are cused by suddenly applied or suddenly removed forces are exceptions.) In addition, nearly all pendulum and balance-wheel oscillations in clocks are of this vibrational type, and the toys mentioned here are models of all that [28].

- The walking dog is an example of a toy animal having legs freely pivoted to the body. When put an the table and pulled forward by a string, the toy walks in definite steps, accompanied by a sideways Oscillation.
- The put-put boat although driven by a heat source, has many mechanically interesting aspects. It moves forward in reaction to waterjets flowing out of tubes at the rear of the boat [28].
- The woodpecker an a rod, consists of a wooden bird attached to a ring by mean of a spring. The ring is loosely attached to a metal rod and may slide down the rod due to gravity But instead of moving down uniformly, it sticks and Slips with the up and down vibrations of the bird, alternatively tilting the ring and making it free to move. This vibration, in turn, is generated by the stick and Slip sliding [29].
- The children's swing is an example of a parametrically excited oscillation, which may be understood by simple mechanical reasoning [30]. It may be considered a modal of parametrically excited vibrations in other fields of physics.
- Notched stick: The rotation of a propeller fixed to the end of a stick by rubbing over notches engraved in the stick seems to be a miracle. But it may be reduced to the effect of mechanical mechanisms [32,32].

4.5 Catastrophic-toys

By this we understand toys exhibiting phase transition like, or generally, in the Sense of R. Thom [33], catastrophic behaviour. The importance of this topic is, above all, due to its modal character for very important phenomena in the environment.

- The cracking frog: This is a very simple toy shaped like a frog. It has a flexible steel plate which produces a cracking noise when a certain bending force is applied to it, and which goes back to its original form when it is released. This effect is similar to a phase transition [34].
- The "bird in shell" consists of a hollow metal egg divided into four vertical sections hinged at the bottom of a circular base and held together by a rubber band. A push an a thumb plunger Sets the shell in rotation. At a certain rotation rate the shell suddenly opens revealing a bird standing in the center. The shell closes again when the rotation rate slows down by friction. This phenomenon is a dynamical analogy of a first Order phase transition [35].

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