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Analysis of the Young Physicists Tournament problems supported by multimedial tools

Abstract: In the contribution there is a physical analysis of the selected experimental problems of the Young physicists' tournament presented. The analysis is realized with the help of videoclips, animations, JAVA applets and computer-based measurements. The complex use of these tools enables students' deeper understanding of the examined problems. At the same time it is an efficient means for students to present and argue for their own solutions within the competition.

Key words: young physicists tournament problems, multimedia presentation,

1 Young Physicists' Tournament

The International Young Physicists' Tournament (IYPT) is a competition among teams of secondary school students in their ability to solve complicated scientific problems, to present solutions to these problems in a convincing form and to defend them in scientific discussions, called Physics Fights (PF). The problems are formulated by the International Organizing Committee (IOC) and sent to the participating countries at the beginning of the school year.

The IYPT team is composed of five secondary school students. All teams participate in five Selective PFs. Selective PFs are carried out according to a special schedule, if possible, no team meets another team more than once. This schedule should be known before numbers are ascribed to the teams by lot. The best teams participate in the Final PF. The PF is carried out in three (or four) Stages. In each Stage, a team plays one of the three (four) roles: Reporter, Opponent, Reviewer (Observer). In the subsequent Stages of the PF, the teams change their roles.

The Reporter presents the essence of the solution to the problem, attracting the attention of the audience to the main physical ideas and conclusions.

The Opponent puts questions to the Reporter and criticizes the report, pointing to possible inaccuracy and errors in the understanding of the problem and in the solution. The Opponent analyses the advantages and drawbacks of both the solution and the presentation of the Reporter. The discussion of the Opponent should not become a presentation of his/her own solution. In the discussion, the solution presented by the Reporter is discussed.

The Reviewer presents a short estimation of the presentations of Reporter and Opponent. **The Observer** does not participate actively in the PF.

During one PF only one member of a team takes the floor as Reporter, Opponent or Reviewer; other members of the team are allowed to make brief remarks or to help with the presentation technically. No member of a team may take the floor more than twice during one Selective PF or, as Reporter, more than three times in total during all Selective PFs. During the Final PF any team member can take the floor only once.

After each stage the Jury grades the teams, taking into account all presentations of the members of the team, questions and answers to the questions, and participation in the discussion. Each Jury member shows integer marks from 1 to 10. The mean of the highest and the lowest marks is counted as one mark which is then added to the remaining marks. This sum is used to calculate the mean mark for the team. The mean marks are multiplied by

various coefficients: 3.0 for the Reporter, 2.0 for the Opponent, 1.0 for the Reviewer and then transformed into points.
The performance order in the Stage of a PF and reserved time in minutes is following:

1. The Opponent challenges the Reporter for the problem (1 min.)
2. The Reporter accepts or rejects the challenge (1 min.)
3. Preparation of the Reporter (5 min.)
4. Presentation of the report (12 min.)
5. Questions of the Opponent to the Reporter and answers of the Reporter (2 min.)
6. Preparation of the Opponent (3 min.)
7. The Opponent takes the floor, maximum 5 min. (E) and discussion between the Reporter and the Opponent (15 min.)
8. Questions of the Reviewer to the Reporter and the Opponent and answers to the questions (3 min.)
9. Preparation of the Reviewer (2 min.)
10. The Reviewer takes the floor (3 min.)
11. Concluding remarks of the Reporter (2 min.)
12. Questions of the Jury (5 min.)

Fig. 1: Students scientific discussions in Physics Fights

2 Selected young physicists tournament problems

Filament

There is a significant current surge when a filament lamp is first switched on. Propose a theoretical model and investigate it experimentally.

Suppose the resistance of the cold filament of a bulb at room temperature T_0 is R_0. As soon as the bulb is turned on, a maximum in-rush current $I_{max} = U/R_0$ starts flowing, where U is the constant voltage value. Since I_{max} is quite large (typically of the order of 10 A or more) the corresponding Joule heat makes the temperature T of the filament rise very rapidly. In particular, the resistance R starts to increase quickly according to the power-law parametrization:

$$R = R_0 \left(\frac{T}{T_0} \right)^{1,215} \tag{1}$$

where we obtained the index 1,215 by making a least-squares fit to the available data on the resistivity of tungsten in the range 300 – 3655 K. Since the heating process is quite fast, no significant heat energy can leave the system until the temperature rises to a reasonably high value of the order of 1500 K. In the following we shall refer to this whole process as adiabatic heating, and as you will see this is determined mainly by the heat capacity of the filament. Thereafter a noticeable amount of heat starts to leave the system via Stefan's radiative channel. Finally, a steady-state temperature T_s is reached when the input electrical power is exactly balanced by the radiative component from the filament together with the conductive losses in the leads and convective losses, if any, in the surrounding gas. Then the rated wattage P of the bulb becomes

$$P = \frac{U^2}{R_S} = \frac{U^2}{R_0 (T_S / T_0)^{1,215}} \tag{2}$$

where R_s is the resistance in the steady state. This equation can be readily solved for the steady-state temperature T_s as:

$$T_S = T_0 \left(U^2 / R_0 P \right)^{1/1,215} \tag{3}$$

Suppose for a moment that the temperature of the filament had risen from T_0 to T_s without any heat leaving the system, i.e. adiabatically, then obviously the corresponding time τ_A needed for the heating would have been the shortest possible. Of course, in reality significant heat does leave the filament through radiation, conduction and convection, implying that the actual switching time τ becomes larger, i.e.

$$\tau > \tau_A \tag{4}$$

The theoretical evaluation of τ is very complicated because it requires solving the full heat equation containing heat capacity, resistance, emissivity, losses, etc. For our purposes it will be sufficient to evaluate τ_A. As you can guess, a bulb cannot provide light before at least the time τ_A has elapsed, and that is why τ_A is a lower bound on the switching time.

Let us ask ourselves how the temperature rises with time during the adiabatic heating of the filament. The answer will be obtained by solving the simplified heat equation in which the amount of energy produced in the filament per unit time by Joule heating goes wholly into raising the temperature:

$$mc\frac{dT}{dt} = \frac{U^2}{R_0 \left(\frac{T}{T_0} \right)^{1.215}}$$

$$mc\frac{dT}{dt} = \frac{U^2}{R} \tag{5}$$

Here M = $\pi r^2 L d$ is the mass of the filament, r the radius, L the length, d the density, C the specific heat, dT=dt the rate of rise of temperature and U^2/R the input Joule heating power at the instant t . However, when we deal with a tungsten filament, because of the enormous range, namely 0– 3000°C, over which the relevant temperature varies. Hence, in the case of electric bulbs C cannot be taken as a constant; rather it should be represented by a suitably parametrized function of temperature which fits the experimentally measured values. In the case of tungsten metallurgists have arrived at the following parametrization in the range 0–3000°C:

$$c = 3R_g \left(1 - \frac{\theta_D^2}{20T^2} \right) + 2aT + 3bT^3 \, J.kg^{-1}.K^{-1} \tag{6}$$

where T is in kelvin, R_g is the gas constant, θ_D – 310 K is a constant called the Debye temperature, a = 4,5549.10^{-3} J.kg^{-1}.K^{-2}, b = 5,778 74 .10^{-10} J.kg^{-1}.K^{-4}.

An adiabatic heating time τ_A we can obtain by solving the heat equation (5)let us rewrite it as:

$$dt = \frac{R_0 mc}{U^2} \left(\frac{T}{T_0} \right)^{1.215} dT \tag{7}$$

$$dt = \frac{R_0 m}{U^2 T_0^{1.215}} \left[3R_g \left(1 - \frac{\theta_D^2}{20T^2} \right) + 2aT + 3bT^3 \right] T^{1.215} dT \qquad (8)$$

Let us consider: T_0 = 300 K, T = 2900 K, m = 2,68.10^{-5} kg, R_0 = 10 Ω, U = 120 V , we can calculate adiabatic switching time:

t_A = 0,06s

Planck`s law gives the intensity of radiation I at a single frequency ν, as:

$$I(\lambda, T) = \frac{2\pi hc^2}{\lambda^5} \frac{1}{e^{-\frac{hc}{\lambda kT}} - 1} \qquad (9)$$

Where c is the speed of light, k is the Boltzmann constant, T is the absolute temperature of the emitter, and h is the Planck`s constant. If we can consider the filament as the black body, for energy of radiation we can write, due to Stefan – Boltzmann law:

$$E(T) = \int_0^\infty I(\lambda, T) dT = \sigma T^4 \qquad (10)$$

where σ is Stefan’s constant.

For an illustration of this phenomenon we are using an applet (Fig.2).

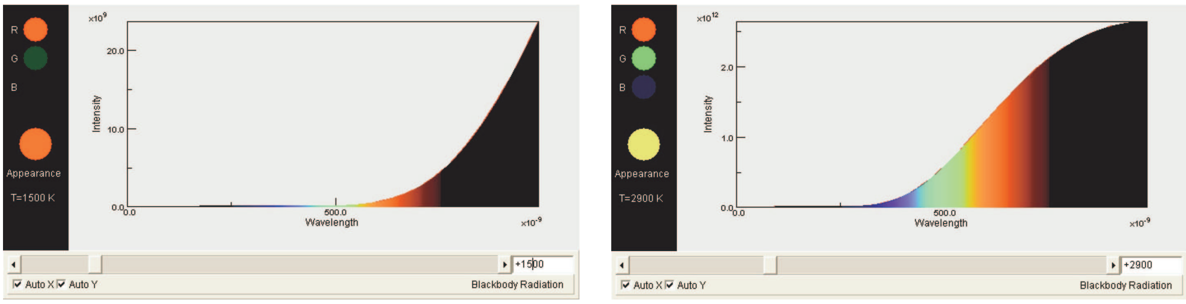

Fig. 2: An applet with simulation of the black body radiation,
for the filament temperature of 1500 K and 2900 K.

Switching time measurement was arranged in computer based laboratory with Coach software. The typical current (resistance) time dependence is in Fig 3.

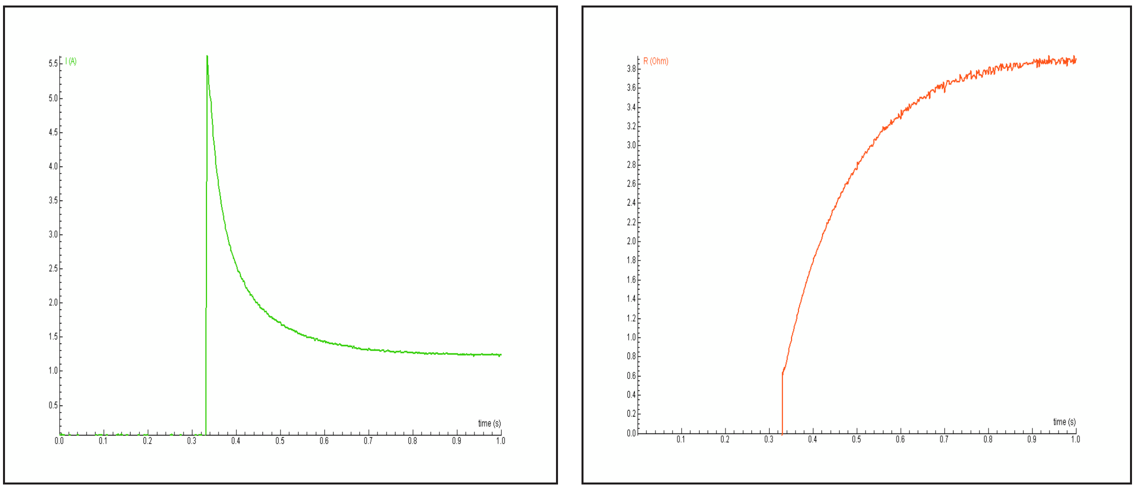

Fig. 3: Current (Resistance) versus time dependence for the incandescence filament.

Steam Boat

A boat can be propelled by means of a candle and metal tubing with two open ends. Explain how such a boat is propelled and optimize your design for maximum velocity.

The putt-putt boat is a little toy that has fascinated everyone from children to physicists for over a hundred years now. This boat is powered, not by a conventional heat engine, but by a motor that can be termed a pulsating water jet engine (Fig. 4). The propulsion mechanism that drives the putt-putt boat uses simple physical principles in an ingenious way.

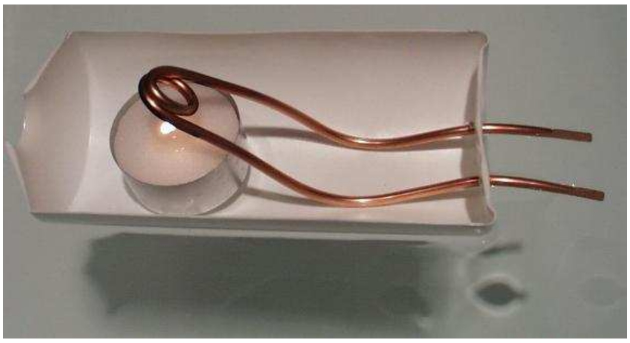

Fig. 4: The Put - put boat.

Our steam engine eats made from hollow metals tube (Fig. 5) turn by three windings, with estuary below water level. If the windings are warm up by tea candle flame, water vapor treat out water from the tube. Steam in colder part of the tube condenses, and water is suck inside the tube.

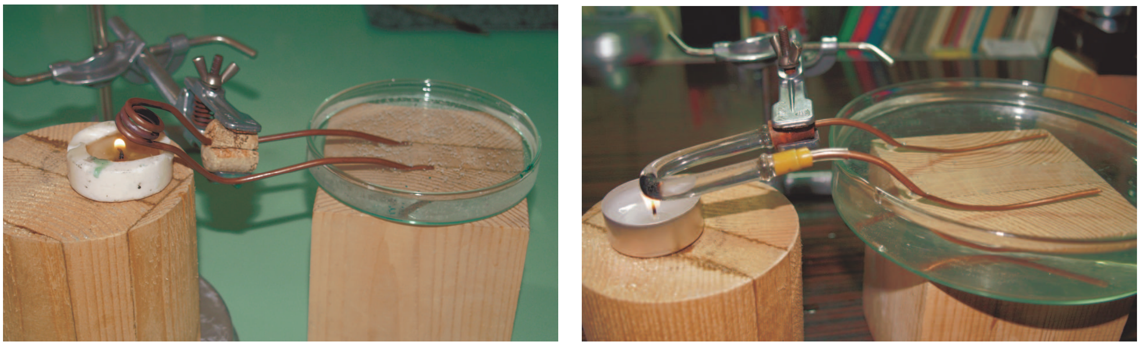

Fig. 5: Copper tube with windings, glass U–shape tube model of the put – put boat.

During suction water from the outside enters the pipes; during the exhaust phase an equal amount of water is thrown out. The boat is propelled forward by the alternate suction and ejection of the fluid across its pipes' orifice. Even though the net mass flow is zero, the differences in the flow patterns during outflow and inflow cause a net forward thrust; thrust is mainly produced during ejection phase. During the outflow, the flow is an axi-symmetric jet confined to a narrow domain and does not diverge much for reasonable distances. The inflow of the same magnitude does not produce an equal and opposite thrust, and is small compared to the thrust produced during exhaust.

For our research activities we construct the glass model of the put-put boat. Glass U - shape tube is mounted in stand. Below the centre of the glass tube we placed the tea candle. Glass U – shape tube is connected to the copper hollow tubes, with the estuaries below the water level in the dish. For the observation of the water motion we pour the powder into the water.

The simple model of the interesting children toy enables to students experimental observation of the influence of fundamental physical factors on simple steam engine. From created video files we try to establish the frequency of the pulses.

Slinky

Suspend a Slinky vertically and let it fall freely. Investigate the characteristics of the Slinky's free-fall motion.

When a spring is hung by one end such that it extends by its own weight and then released, the lower end will not fall for a moment but will hang briefly suspended in the air. Let's idealize the system as a massless spring of zero length with equal masses attached to each end (Fig. 6). In the absence of gravity, if the system were released from being stretched, it would undergo symmetrical motion about the center of mass as shown by.

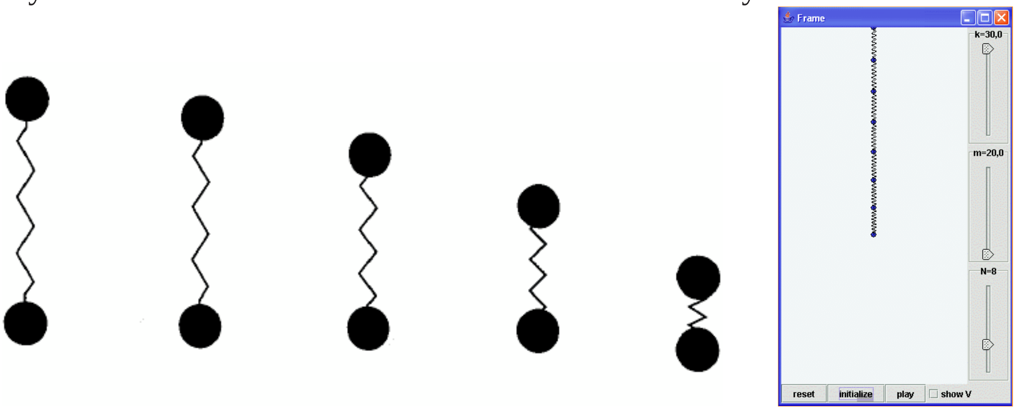

Fig. 6: Slinky`s free fall and its applet simulation.

We can split the system in half, with each half undergoing sinusoidal motion. In anticipation of halving the system, denote the total spring constant K/2 and the total mass 2M. Thus, the spring constant and mass of a half are just K and M, respectively.
The motion from the time of release ($t = 0$) is given by:

$$y = -\mathrm{A} \cos \omega t \qquad (11)$$

with A the distance from the end of the stretched system to the center, and $\omega = (\mathrm{K/M})^{1/2}$.
A Slinky is a "tightly wound spring," meaning the unstretched coils touch each other, so harmonic motion will only last for a relatively small time (about one quarter of the period). A Taylor expansion of the cosine function gives, to second order, $y = -\mathrm{A} \cos\omega t \sim -\mathrm{A} + \mathrm{A}(\omega t)^2/2$, which upon substituting for ω is $y \sim \mathrm{A} - \mathrm{AK}t^2/2\mathrm{M}$.
Now we consider gravity and hold the upper mass fixed, allowing the lower mass to hang at rest at its equilibrium position. From Hooke's law, the displacement from the center of the spring is $\mathrm{A} = \mathrm{M}g/\mathrm{K}$, which also corresponds to the amplitude of the oscillation that begins when the spring is released. Upon substituting for A in the second order term above, we have $y \sim \mathrm{A} - gt^2/2$.
This expression gives the approximate location of the lower mass with respect to the center of the spring. But the center of mass falls according to $y_{\mathrm{cm}} = g\, t^2/2$. The displacement of the lower end of the spring with respect to the stationary origin is $y + y_{\mathrm{cm}} \sim \mathrm{A}$.
In other words, the end remains nearly motionless for a short while, about one quarter period.
For the visualization of the free fall slinky motion we modify the applet from the pages of prof. Fu-Kwun Hwang from Dept. of Physics, National Taiwan Normal University.

CONCLUSION

In the future we plan to continue in student's group preparation for the Young Physicists tournament with the further teacher education activities and with deeper interest to student's multimedia presentation of actual problems.

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