Presentation of the book

Fascinating Problems for Young Physicists: Discovering Everyday Physics Phenomena and Solving Them

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The 11th Conference of the Balkan Physical Union
Belgrade, 28 August – 1 September 2022

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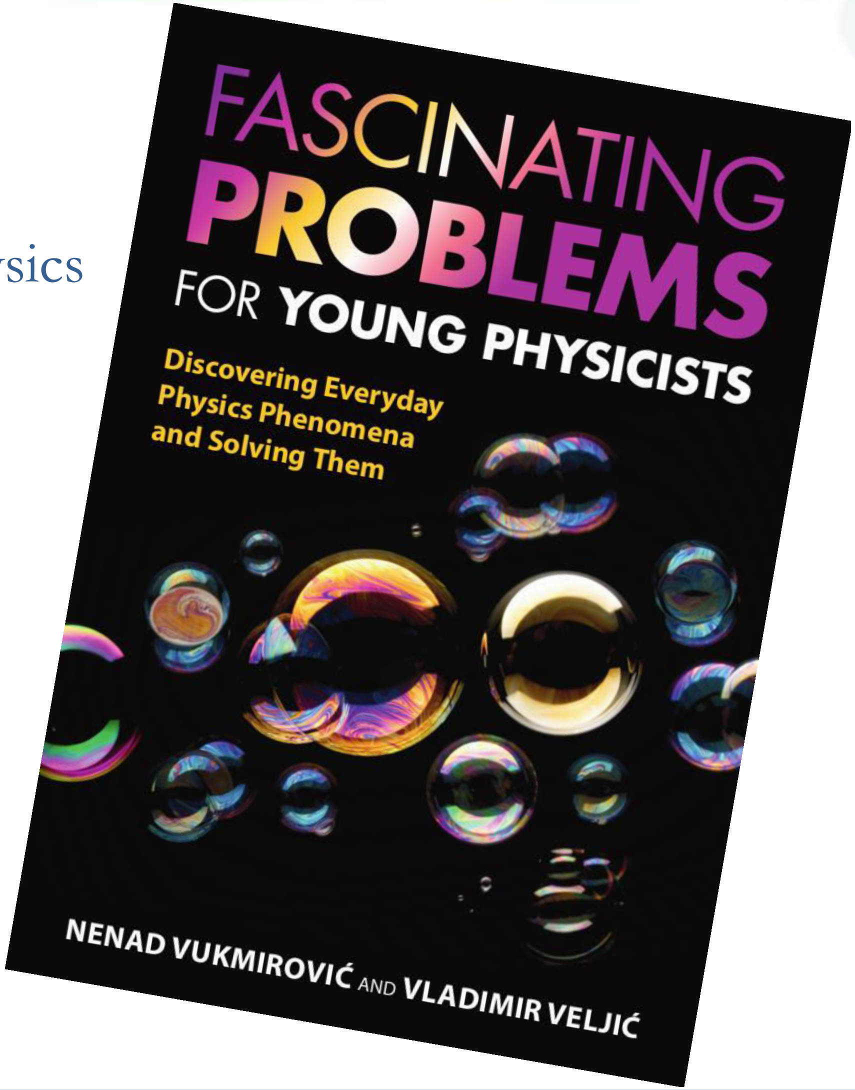
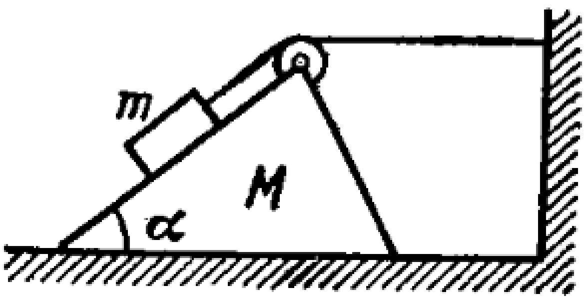
Basic Info

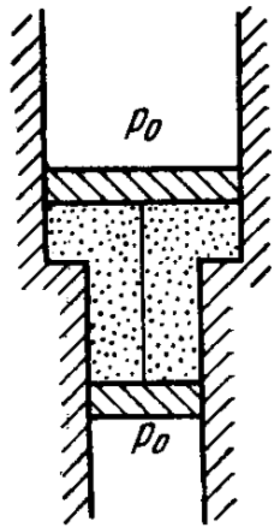
- Published in July 2022 by Cambridge University Press.
- Collection of problems on physics in the world around us.

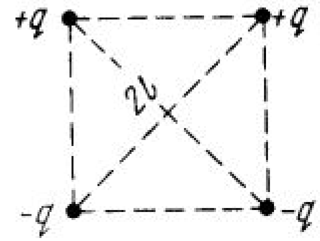


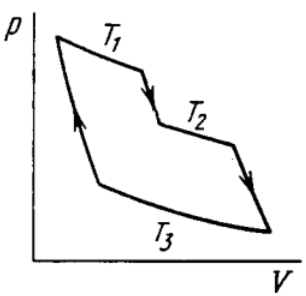
Motivation (1)

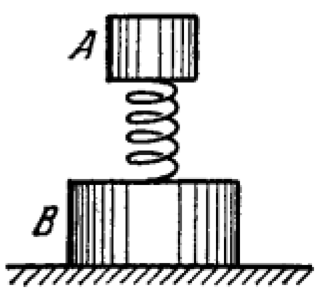
- Physics describes nature…
- …but we seem to forget that.
- Collections of physics problems typically consider a rather restricted set of model systems.

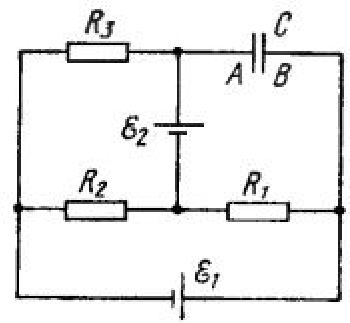










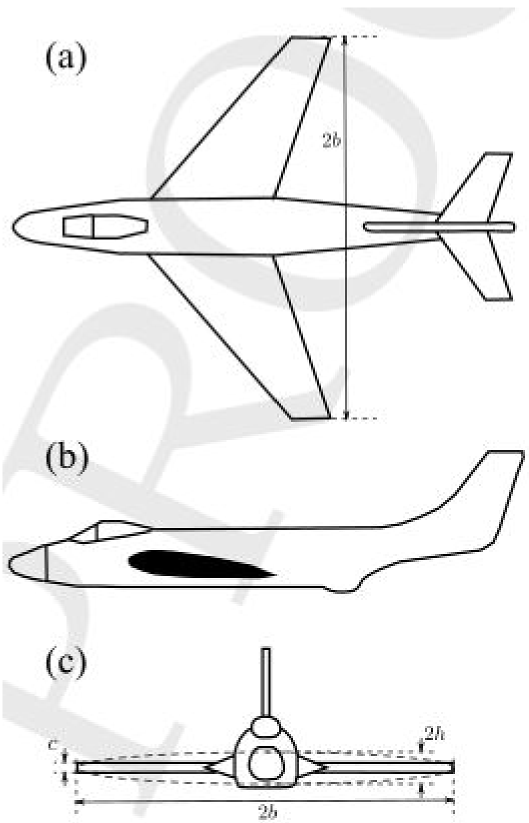


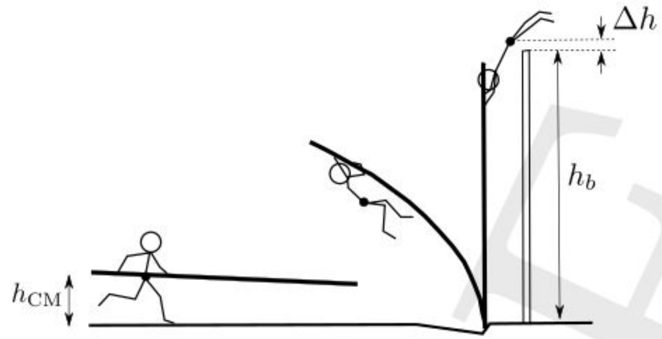
Motivation (2)

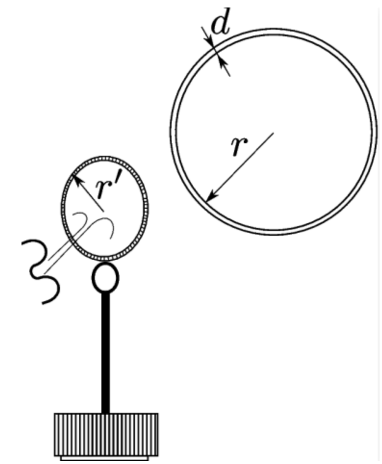
- This is the case in all classical collections of physics problems, such as, e.g.
  - I. E. Irodov, Problems in General Physics, Mir Publishers, Moscow (1981).
  - P. Gnädig, 200 Puzzling Physics Problems: with Hints and Solutions, Cambridge University Press (2001).
  - О. Я. Савченко, Задачи по физике, Новосибирский государственный университет (1999).
- The books that describe the world around us do it mainly on qualitative level, e.g.
  - L. Bloomfield, How Things Work: The Physics of Everyday Life, Wiley (1997).
- Our book bridges this gap.

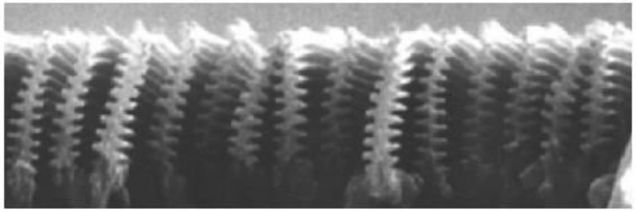
Motivation (3)

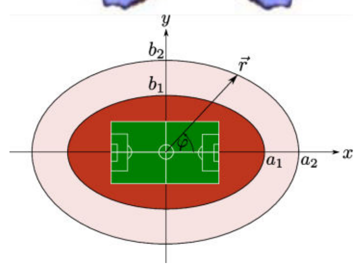
❖ The world around us:

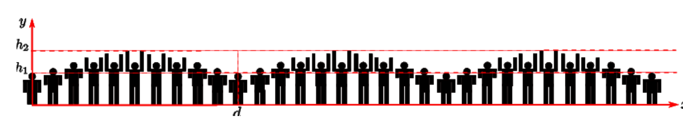












Content of the book (1)

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Content of the book (2)

- 42 problems divided into tasks
- A total of around 333 tasks
- The working title (in Serbian) was

  Збирка

  Занимљивих

  Задатака
- Motivation for the problems comes from the world around us rather than from the branches of physics, hence 6 chapters:
  - Human
  - Machines
  - Sport
  - Nature
  - Energy
  - Miscellaneous

Problems in the book (1)

- Problems where knowledge of general physics is applied to phenomena from life.
- The problems are formulated in such a way to guide the student to learn about the physics of the phenomenon going step-by-step by solving the problem.
- First tasks in the problem are typically easier and final tasks become more difficult.
- Detailed solutions are given. However, students are advised to consult the solutions only when necessary and to use them only as hints.

Problems in the book (2)

- Level of the problems
  - talented high-school students (problems similar to those at national physics competitions and physics olympiads)
  - 1^{st} and 2^{nd} year undergraduate courses in general physics
  - easiest parts of the problems suitable even for elementary school students

- Most tasks have "closed form" solutions with all the data given in the problem and the physical model of the system specified in the task.
- An 'order of magnitude' estimate is required in a few tasks.

- Jupyter notebooks accompany each problem.

Problems in the book (3)

- Example of outcomes of solving the problem
  - Why are the world records in high jump, long jump or pole vault at the specific lengths or heights?
  - What is the relation between the mass of the animal and its expected lifetime?
  - What is the efficiency limit of wind turbines?
  - How do we see?
  - Why we see nice butterfly colors?

- The tasks guide the reader to recognize and understand the basics of the main physical effects behind the phenomenon and stimulate the reader to investigate the phenomenon further.

Problem creation

- ❖ Majority of problems is original. Few problems were adapted from other sources. The authors presented parts of several problems at physics competitions in Serbia (2012-2013, 2015-2019).

- ❖ How to create a problem?
  1. Interesting phenomenon from real life.
  2. Search for textbooks or physics education papers about the phenomenon.
  3. Identification of main physical effects of the phenomenon.
  4. Simplification in order to focus on physics rather then math.
  5. Formulation of the tasks:
     - description of the phenomenon.
     - definition of the physical model and approximations.
     - next task is often logically connected to the previous one.

Sample problem (1)

❖ Physics of jumping disciplines in athletics.

Problem 15 How Far Can Athletes Jump?

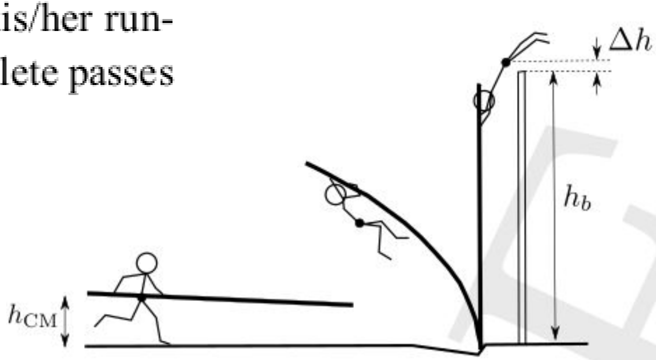
What are the world records in the pole vault, the high jump, and the long jump?

We investigate in this problem how long or how high athletes can jump using different techniques. The mass of an athlete is $m = 75.0\,\mathrm{kg}$. The position of the athlete's center of mass is $h_{\mathrm{CM}} = 0.900\,\mathrm{m}$ above the ground. Gravitational acceleration is $g = 9.81\,\mathrm{m/s^2}$. Unless otherwise stated, neglect air resistance.

Sample problem (2)

- Pole vault
  - transformation of kinetic energy into potential energy.

(a) We consider the pole vault first. In the course of a pole vault the athlete first runs and reaches a speed of $v_1 = 10.0\,\mathrm{m/s}$. The athlete then uses an elastic pole to efficiently convert kinetic energy into potential energy (Figure 3.1). In pole vault competitions, the goal is to jump above a bar that is in a horizontal position at a height of h_b above the ground. Assume that the speed of the athlete in the moment of passing above the bar is negligible (which is a justified assumption since the athlete can push off the pole in that moment and therefore does not need a significant speed to pass above the bar) and that the center of mass in that moment is $\Delta h = 0.100\,\mathrm{m}$ above the bar. What will be the height h_b of this jump if the total kinetic energy that the athlete had at the end of his/her run-up was converted into potential energy in the moment when the athlete passes above the bar?

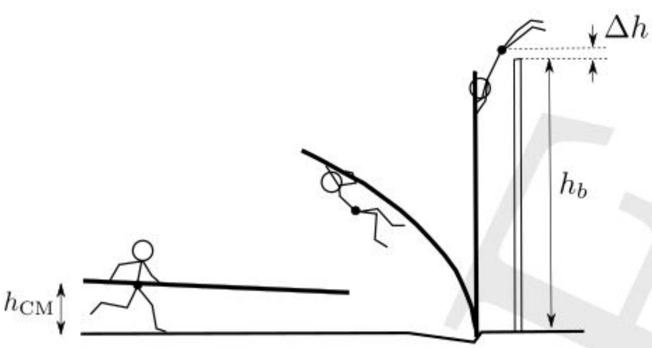


Sample problem (3)

- Pole vault
  - transformation of kinetic energy into potential energy.

Solution of Problem 15

(a) Conservation of energy yields $\frac{1}{2}mv_1^2 + mgh_{CM} = mg(h_b + \Delta h)$, implying $h_b = h_{CM} - \Delta h + \frac{v_1^2}{2g} = 5.90\,\text{m}$. This height is somewhat shorter than the pole vault world record for men of 6.20 m set by Armand Duplantis from Sweden on March 20, 2022, while it is larger than the women's world record of 5.06 m set by Yelena Isinbayeva from Russia on August 28, 2009.

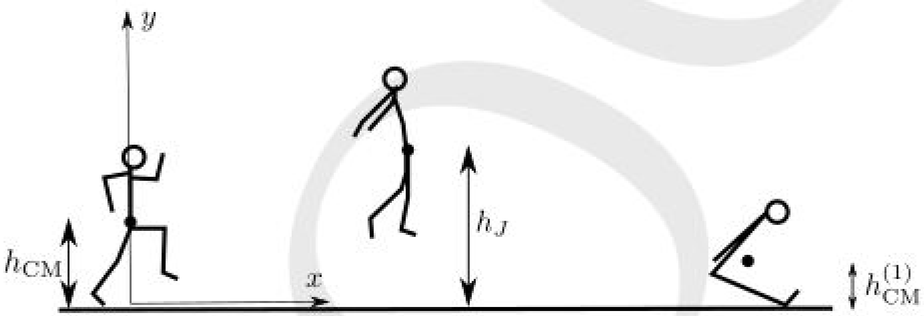


Sample problem (4)

- Long jump - idealized model.

In the long jump, the athlete runs, reaching speed v_0, and then jumps as shown in Figure 3.2.

(b) Find the maximal length of the jump for an athlete who has reached a speed of $v_0 = 10.0\,\mathrm{m/s}$ during the run-up. Assume that the athlete does not lose kinetic energy at the moment of takeoff and that the center of mass is at the same height in the moment of landing as in the moment of takeoff. What is the highest position of the athlete's center of mass during the jump in which the maximal length is reached?



Sample problem (5)

❖ Long jump - idealized model, solution.

(b) We define α as the angle between the athlete's velocity and the horizontal at the moment immediately after takeoff. The dependence of the coordinates of the center mass on time is:

$$x(t) = v_0 t \cos\alpha, \tag{3.2}$$

$$y(t) = h_{\mathrm{CM}} + v_0 t \sin\alpha - \frac{1}{2} g t^2. \tag{3.3}$$

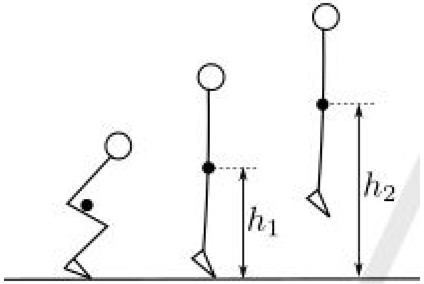
At the moment of landing we have $y(t_d) = h_{\mathrm{CM}}$. Using equation (3.3) it follows that $t_d = \frac{2v_0 \sin\alpha}{g}$. By putting this expression in equation (3.2) and using the trigonometric identity $\sin(2\alpha) = 2\sin\alpha\cos\alpha$ we find that the length of the jump is $D = x(t_d) = v_0^2 \frac{\sin(2\alpha)}{g}$. This expression is maximal when $\sin(2\alpha) = 1$; that is, $\alpha = 45^\circ$. The maximum is equal to $D_m = \frac{v_0^2}{g} = 10.2\,\mathrm{m}$. The athlete reaches the highest point of the trajectory in the moment $t_1 = \frac{v_0 \sin\alpha}{g}$. In that moment, using equation (3.3), we find $y_m = y(t_1) = h_{\mathrm{CM}} + \frac{v_0^2 \sin^2\alpha}{2g}$ – that is, $y_m = h_{\mathrm{CM}} + \frac{v_0^2}{4g} = 3.45\,\mathrm{m}$. The jump is longer than the women's long jump world record of 7.52 m set by Galina Chistyakova from the Soviet Union on June 11, 1988. It is also longer than the men's long jump world record of 8.95 m set by Mike Powell from the USA on August 30, 1991. It is noticeable as well that the highest position of the center of mass is higher than the world record in the high jump.

Sample problem (6)

- "Vertical" kinetic energy produced at take off.

The length and the height obtained in part (b) are larger than the world records in the long jump and the high jump. Therefore, the assumptions introduced are not fully realistic.

The assumption that the kinetic energy of the athlete does not change while the velocity changes its direction at takeoff is not realistic. For this to happen, a significant force must act on the athlete vertically. It is not easy to produce such a force.



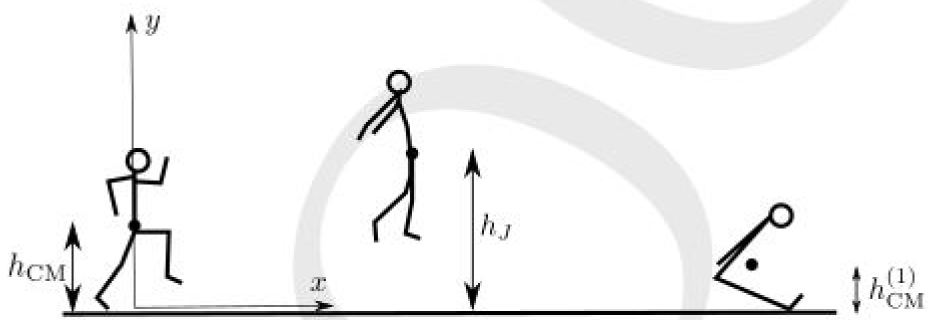
(c) To establish the amount of kinetic energy that the athlete can produce at takeoff, we consider a vertical high jump without the run-up. During this jump the athlete starts from a squatting position pushing the feet off the ground. At the moment when the feet leave the ground, the athlete is in a vertical position, as shown in Figure 3.3. If the athlete jumped to a height of $h_2 - h_1 = 90.0\,\mathrm{cm}$ (Figure 3.3), what was the athlete's kinetic energy immediately after takeoff?

(c) Let T be the kinetic energy of the athlete immediately after takeoff. Conservation of energy leads to $T + mgh_1 = mgh_2$, where h_1 is the position of the center of mass at the moment of takeoff, while h_2 is the highest position of the center of mass. We then find $T = mg\,(h_2 - h_1) = 662\,\mathrm{J}$.

Sample problem (7)

- Realistic long jump model.

(d) We consider next an athlete competing in the long jump who reaches a speed of $v_0 = 10.0\,\mathrm{m/s}$ during the run-up. Assume that the athlete increases the kinetic energy during takeoff by the amount determined in the previous part of the problem. The athlete accomplishes this by producing the vertical component of the velocity, while the horizontal component remains the same. To jump longer, the jumper changes the position of the body before landing so that the center of mass is $h^{(1)}_{\mathrm{CM}} = 0.700\,\mathrm{m}$ above the ground in the moment of landing (Figure 3.2). What is the length of the jump under these assumptions?



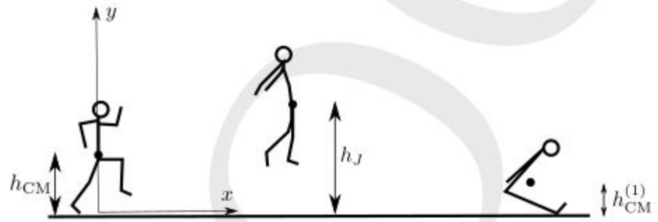
Sample problem (8)

❖ Realistic long jump model - solution.

(d) The time from takeoff to the moment of reaching the highest point in the trajectory is $t_a = \sqrt{\frac{2(h_J - h_{CM})}{g}}$, while the time from reaching this point to landing is $t_b = \sqrt{\frac{2\left(h_J - h_{CM}^{(1)}\right)}{g}}$. The velocity of the jumper has only the horizontal component v_0 at the highest point of the trajectory. Conservation of energy applied to the moment immediately after takeoff and the moment when the athlete is in the highest point of the trajectory yields $\frac{1}{2}mv_0^2 + T + mgh_{CM} = \frac{1}{2}mv_0^2 + mgh_J$ – that is, $h_J = h_{CM} + \frac{T}{mg}$. The length of the jump is $D = v_0\,(t_a + t_b)$ – that is,

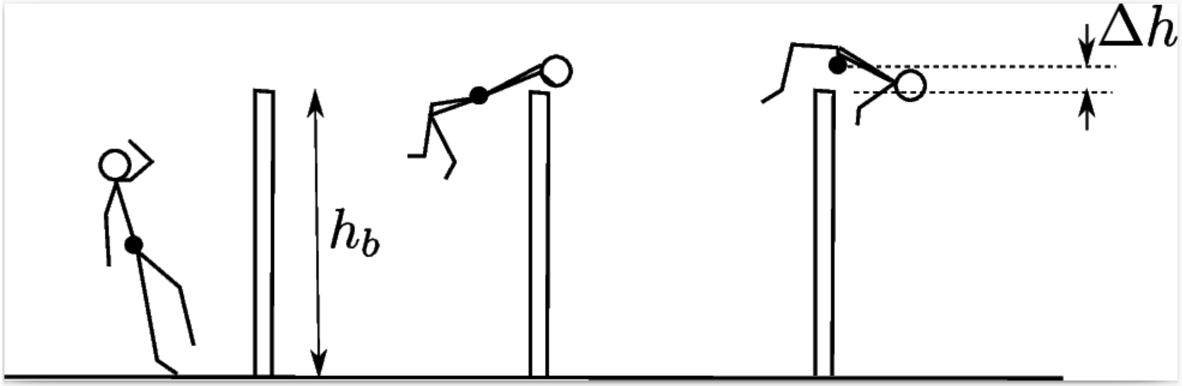
$$D = v_0 \cdot \left(\sqrt{\frac{2\,(h_J - h_{CM})}{g}} + \sqrt{\frac{2\left(h_J - h_{CM}^{(1)}\right)}{g}} \right) = 9.02\,\mathrm{m}. \qquad (3.4)$$

The result is very close to the men's long jump world record, while it is longer than the world record for females.



Sample problem (9)

- Part (e) – long jump including the effect of wind
- Part (f) – high jump



Sample problem (10) – Jupyter notebook

jupyter Problem15 Last Checkpoint: 09/04/2021 (unsaved changes)

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PROBLEM 15

Solution of part (a)

In [1]:

```
# The position of the center of mass in [m]
hcm=0.9

# The position of the center of mass over the bar in highest position in [m]
deltah=0.1

# The speed of the athlete in [m/s]
v1=10.0

# Gravitational acceleration in [m/s^2]
g=9.81

# The height of the jump in [m]
h=v1**2/2/g+hcm-deltah

print("The height of the pole vault jump is h = %4.2
```

```
The height of the pole vault jump is h = 5.90 m.
```

Solution of part (b)

In [2]:

```
# The speed of the athlete in [m/s]
v0=10.0

# The length of the long jump in [m]
D=v0**2/(g)

# The highest position of the athlete during this jump in [m]
ym=hcm+v0**2/(4*g)

print("The maximal length of the long jump is D = %4.1f m." %D)

print("The highest position of the athlete during the long jump is ym = %4.2f m." %ym)
```

```
The maximal length of the long jump is D = 10.2 m.
The highest position of the athlete during the long jump is ym = 3.45 m.
```

Instead of conclusion

- The problems from this book will guide the students to recognize the laws of physics in the world around us.
- The students will deepen their knowledge of physics by solving the problems.
- The book will introduce a fresh perspective to the use of problem solving in physics teaching.