Mathematical Grammar School
a school with the High National Distinction status

The Mathematical Grammar School Cup

Physics Competition

28.06.2022.

Instructions:

1. *Duration of the competition is* 3h. *Maximum number of points is* 80.
2. *Use the answer sheet only to give answers to* ***all*** *the questions.*
3. *Use of calculators is allowed. If needed assume the gravitational acceleration to be* $10\ ^{m}/_{s^2}$.
4. *It is not allowed to write on anything other than the answer sheet, notebook and the paper with questions.*
5. *When finished, turn in the answer sheet and the notebook.*

Good luck!☺

Circle the correct answer

1. *(1 point)* Identify the physicist who does not fall into the following group of four founders of optics.

(A) Willebrord Snellius
(B) Alessandro Volta
(C) Augustin-Jean Fresnel
(D) Pierre de Fermat
(E) Isaac Newton

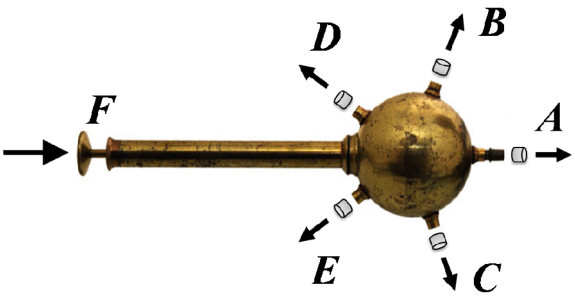
2. *(1 point)* Expressed via SI base units, the speed of light in vacuum has the following numeric value:

(A) $299\,792\,458$ km/s
(B) $299\,792.458$
(C) $299.792\,458$ m/s
(D) $299.792\,458$
(E) $299\,792\,458$

3. *(1 point)* Square root of the product between: {one SI unit of electric charge divided by electric voltage} and {one SI unit of magnetic flux divided by electric current} gives:

(A) one unit of hertz (1 Hz)
(B) one SI base unit of length
(C) 2π units of hertz (2π Hz)
(D) one SI base unit of time
(E) one SI derived unit of speed

4. *(1 point)* A spherical container (hollow metal brass ball), fixed in gravity-free space and entirely filled with static ideal liquid, has five identical holes, all plugged with five identical stoppers. Applied force F, acting on the tube piston, as illustrated in the figure, is gradually increased to put pressure inside the container. The increased pressure may eventually make the liquid streams out by ejecting the stoppers. If that is made to happen, then



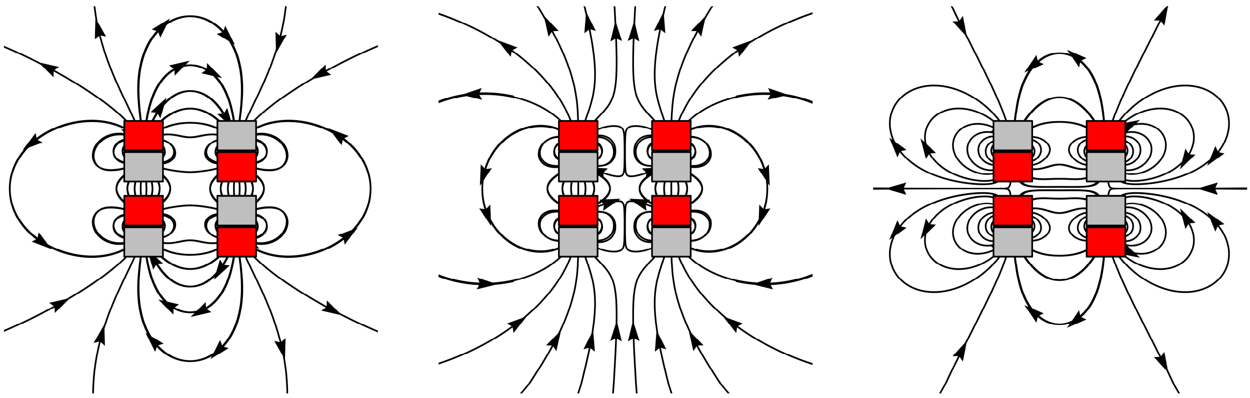
(A) the five stoppers are ejected in the following order: first A, then B and C instantaneously, then D and E instantaneously.
(B) only the stopper A gets ejected.
(C) all the five stoppers get ejected instantaneously.
(D) the five stoppers are ejected in the following order: first E and D instantaneously, then C and B instantaneously, then A.
(E) all but the stopper A get ejected.

5. *(1 point)* When the sun is behind dark clouds and there are gaps in the clouds, you will often see sunlight "fanning" out from the gaps as shown in the given photograph. Though the rays are closely parallel but we see them diverging as they approach the earth. Which one of the following statements most suitably explains this effect?

(A) Distant objects appear smaller than nearer objects.
(B) Sunrays are actually radiated from the sun radially.

(C) This is an atmospheric optical phenomenon due to the geometry of the celestial sphere.
(D) Light bends at sharp corners of opaque object that it encounters.
(E) None of those above applies.

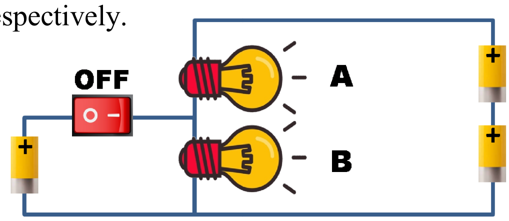
6. *(1 point)* The figure shows three cases of the orientations of four immobile identical magnets in vacuum. Based on the depicted induction lines of magnetic field, as well as the orientation of these magnets, assign the logical value (⊤= true, ⊥= false) of correctness of the magnetic field configuration in each of the three cases respecting the order from the left to the right. North (N) and South (S) poles are given in red and gray, respectively.



(A) ⊤⊥⊤ **(B)** ⊥⊥⊥ **(C)** ⊤⊤⊥ **(D)** ⊤⊤⊤ **(E)** ⊥⊤⊤

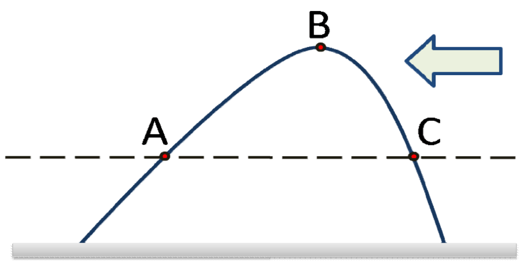
7. *(1 point)* Consider an electric circuit given in the figure with three ideal identical batteries, two identical light bulbs labelled as A and B, together with the electric switch (in the OFF state initially). Then, upon a long time the left part of the circuit is switched on

(A) light intensity of the B and A bulb will drop and raise, respectively.
(B) light intensities of both bulbs will drop.
(C) light intensity of the A and B bulb will drop and raise, respectively.
(D) light intensities of both bulbs will raise.
(E) light intensities of both bulbs will remain unchanged.



8. *(1 point)* A small stone is projected from the ground against the inviscid windy air which introduces some uniformly constant resistance force in the sense of the horizontal arrow only, as shown in the figure visualizing the asymmetric trajectory travelled by the stone. Its highest point is B, reached after the passage through the preceding point A which is in the same horizontal level as the succeeding point C. Which of the following expressions is <u>incorrect</u> in relation to the magnitudes of velocity (v) and absolute numeric values of its horizontal (v_x) and vertical (v_y) components in the A, B, and C points?

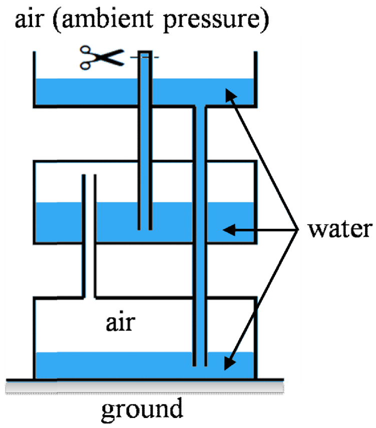
(A) $v_x^{(A)} > v_x^{(B)} > v_x^{(C)}$
(B) $v^{(A)} > v^{(B)}$
(C) $v_y^{(A)} = v_y^{(C)} > v_y^{(B)} \neq 0$
(D) $v^{(A)} > v^{(C)}$
(E) $v_y^{(A)} = v_y^{(C)}$



9. *(2 points)* A helicopter is flying horizontally at slow constant speed. A perfectly flexible uniform cable with its free lower end is suspended beneath the helicopter; the uniform constant air resistive force against the cable motion is not negligible. Which of the following diagrams best represents the stationary cable shape as the helicopter flies through the air to the right?

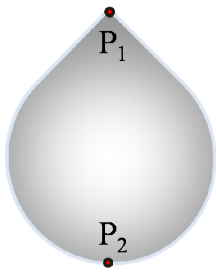
(A) **(B)** **(C)** **(D)** **(E)**

10. *(2 points)* In the following ideal hydraulic system (initially at rest) containing three vertical tubes and three large containers, the closed upper end of the middle tube is suddenly cut off, as shown in the figure. What is going to happen with the water right after?



(A) Nothing particular can be concluded - more information are required.
(B) The water level in the large upper container will start rising.
(C) The water level in the middle tube will start dropping.
(D) The water will start fountaining from the middle tube.
(E) Nothing is going to change - the entire water will remain stationary.

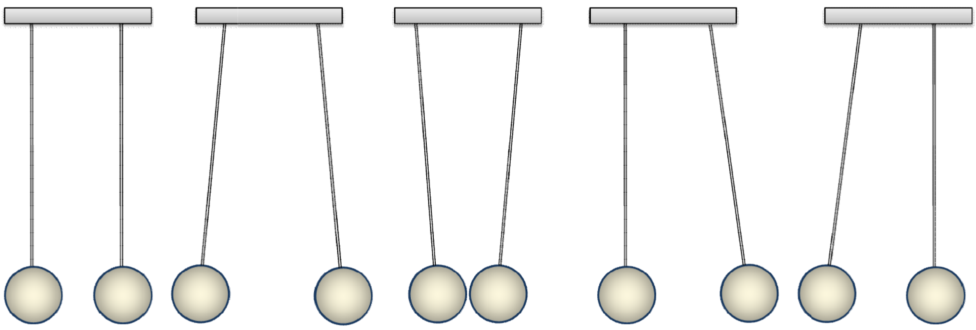
11. *(2 points)* A charged planar metallic body is suspended in air, as given in the figure. The electric potential and the magnitude of the electric field vector at the point P_1 of the body are φ_1 and E_1, respectively. At the point P_2, these quantities are φ_2 and E_2, respectively. If the total charge of the body is positive, which one of the following is correct?



(A) $\varphi_1 = \varphi_2$ and $E_1 > E_2$.
(B) $\varphi_1 > \varphi_2$ and $E_1 > E_2$.
(C) $\varphi_1 = \varphi_2$ and $E_1 < E_2$.
(D) $\varphi_1 < \varphi_2$ and $E_1 < E_2$.
(E) $\varphi_1 = \varphi_2$ and $E_1 = E_2$.

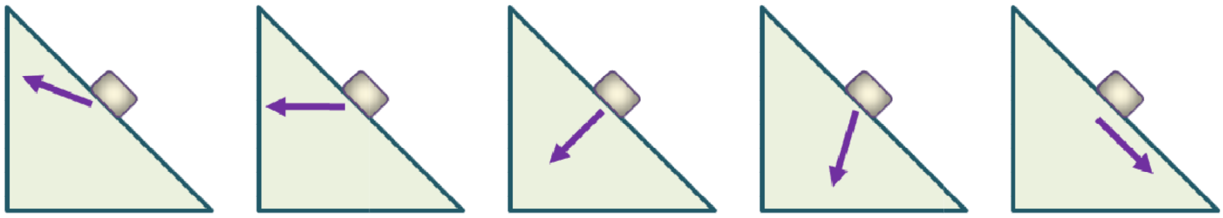
12. *(2 points)* Two electrically neutral conducting lightweight identical balls hang from the non-conducting threads. Choose the diagram in the figure bellow that shows how the balls hang after both of them are charged by touching them with a positively charged rod, but ball 2 picks up more charge than ball 1.

(A) **(B)** **(C)** **(D)** **(E)**



13. *(2 points)* A small body slides down a motionless inclined plane with constant friction, as shown below. Which of the following best represents the direction (arrow) of the total force the body exerts on the plane?

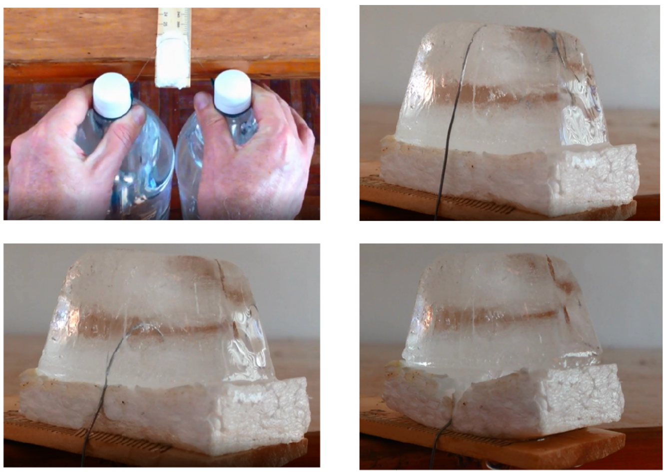
(A) **(B)** **(C)** **(D)** **(E)**



14. *(2 points)* In a novel by Lewis Carroll, Alice in Wonderland enters a fantastical world by catching sight of herself in and out of a mirror. There she finds that everything behind is virtual, distant, yet unattainable for communication. Alice makes a decision to choose a proper type of the mirror in order to produce a real image of herself which would be practically captured in front of the mirror. Which type of the mirror should Alice choose?

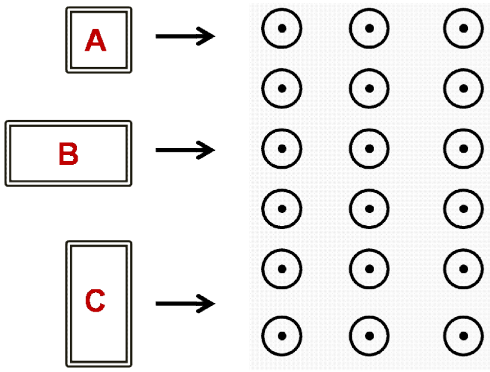
(A) Flat mirror.
(B) Concave spherically-shaped mirror.
(C) Convex spherically-shaped mirror.
(D) Either flat or convex spherically-shaped mirror.
(E) None of those above applies.

15. *(2 points)* Let's witness a curious phenomenon known as *regelation* - a remarkable ability of water's to weld itself. Cut a piece of styrofoam to the size of a small ice piece and lay it on the end of the fixed ruler to place the ice on top, as shown in the figures. Now suspend two heavy bottles over the ice using a wire. The full weight of the two bottles pulling down on the wire exerts a huge amount of pressure on the piece of ice. Over the course of nearly fifteen minutes, the wire is passing right through the ice which "magically" heals itself by refreezing above the wire. Once the wire has passed right through, you can pick the ice up and inspect the frozen tracks where the wire has been, whereas on the other hand, the styrofoam piece will remain irreparably damaged. How would you explain such an emergent phenomenon?



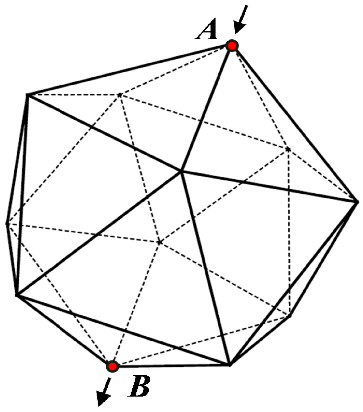
(A) This a pure demonstration of macroscopic quantum tunnelling of the wire passing through the ice given its pure quantum nature, unlike styrofoam.
(B) Ice melts under pressure as the freezing point of water decreases in that case, yet ice does refreeze when the pressure is reduced back to the initial value. For the same reason ice-skaters glide on solid ice as a result of the pressure-induced liquid layer formation that is to refreeze right after his/her passage.
(C) The water molecules (H_2O) possess an unprecedented ability to render its wire-broken covalent bonds between H and O atoms recovered.
(D) All of the above answers apply.
(E) None of the above answers apply.

16. *(2 points)* The figure shows three wired metal loops labelled A, B, and C, each heading towards a region where a uniform static magnetic field exists acting perpendicularly to the plane. The loops move at the same uniform speed and all have the same electric resistance per unit length. Their relative sizes are as indicated: A loop has a square geometry, while B and C loops share identical rectangle geometry, both as twice the surface area of the square loop A. While the three loops are entering the magnetic field region, the loops will have induced electric currents in them. For which loop will the electric current strength be the greatest?



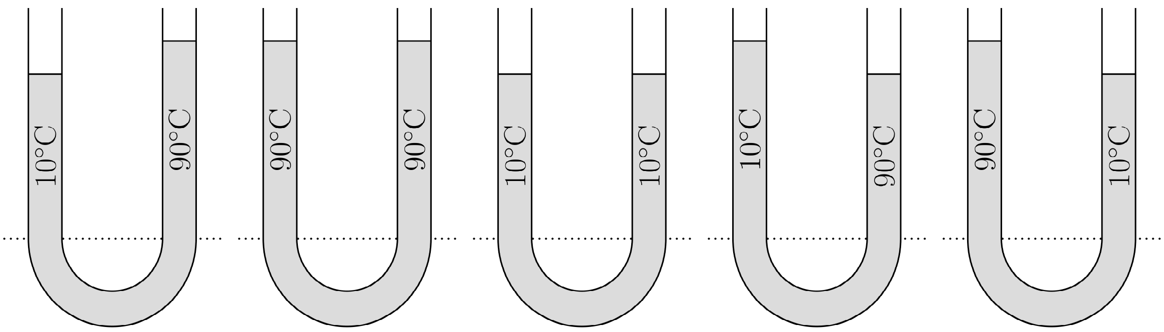
(A) B
(B) A
(C) C
(D) The current is the same in all three cases since the three loops move with the same velocity.
(E) There is no induced current in any of the loops since they move at the uniform speed.

17. *(3 points)* Calculate the effective electric resistance between diametrically opposite vertices, A and B, of a centrally symmetric network that has 20 identical regular triangles as its faces, 30 edges each of electric resistance R, and 12 vertices (nodes), as shown in the figure. The network represents a regular polyhedron known as icosahedron. Vertices A and B are those with the highest node spacing.



(A) $2R$
(B) $R/20$
(C) $10R$
(D) R
(E) $R/2$

18. *(3 points)* U-tube apparatus consists of two vertical glass columns connected with a miniature horizontal connector. Both columns are open to the atmosphere and have the same uniform cross-section together with the connector. The apparatus is filled with some non-evaporating liquid which can be maintained at various temperatures uniformly along the vertical columns, as shown in the figures. The role of the connector is nothing but to transmit hydrostatic pressure from one column to another. The glass does not expand nor contracts with the marked temperatures, that is not the case with the (non-anomalous) liquid. Find the intruder among the five figures.

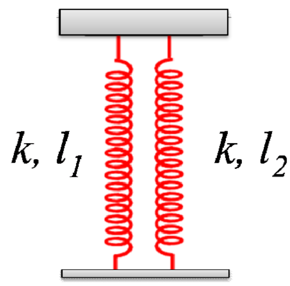


(A) (B) (C) (D) (E)

19. *(3 points)* An annoying feature of a shower curtain is that it blows inwards when one is taking a hot shower, as shown in the figure. Which one of the following statements most suitably explains this effect?

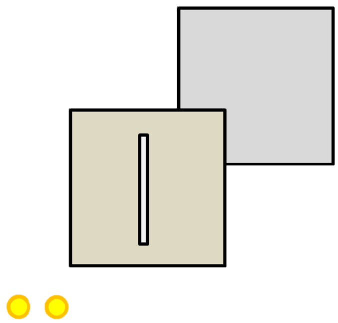
(A) Movement of the shower curtain is due to the attractive electrostatic forces of the polar molecules of the water.
(B) Movement of the shower curtain is due to the attractive electrostatic forces emerged through the unintentional human body rubbing by the curtain.
(C) Movement of the shower curtain is due to the spraying-water-generated pressure difference between the inner and outer surface of the curtain.
(D) All of the above answers apply.
(E) None of the above answers apply.

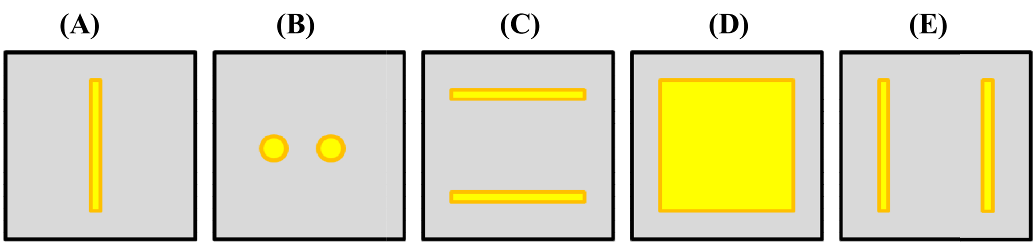
20. *(3 points)* Two ideal springs with equal spring constants k are combined in parallel quite near with each other, as shown in the figure. Their relaxed lengths are l_1 and l_2, respectively. They are attached both to the upper wall and to the lower movable massless platform, the latter of which an external force can be applied to. The combination of the two springs acts like the single spring with the effective spring constant and effective relaxed length as:



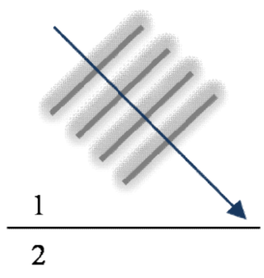
(A) $2k$ and $(l_1 + l_2)/2$
(B) k and $\sqrt{l_1 l_2}$
(C) k and $(l_1 + l_2)/2$
(D) $2k$ and $\sqrt{l_1 l_2}$
(E) $k/2$ and $(l_1 + l_2)/2$

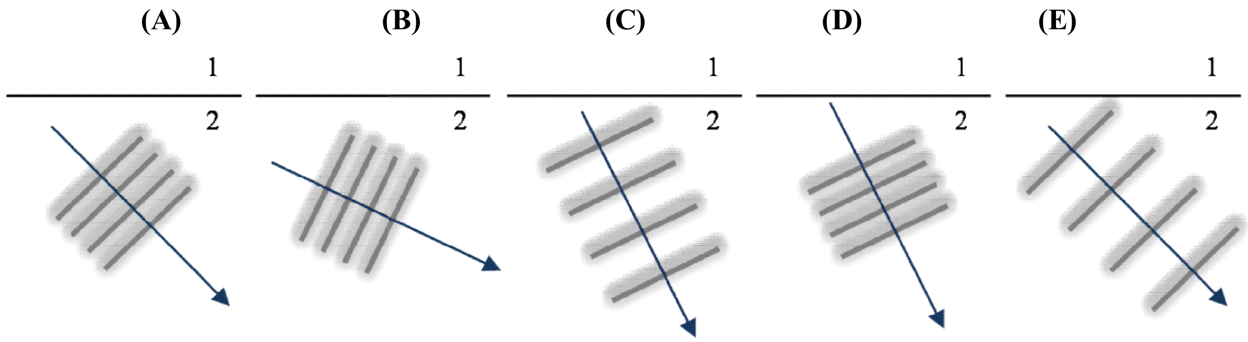
21. *(3 points)* The figure on the right depicts two point-like sources of light illuminating a narrow vertical aperture in a dark screen. The two light sources are hold in front symmetrically with respect to the vertical axis parallel to the aperture line. Neglect the undulatory nature of the light beams. What would you expect to observe on the viewing screen behind?



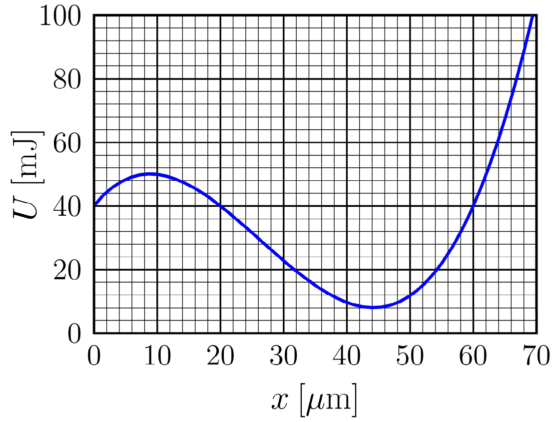


22. *(3 points)* The figure on the right depicts a propagating plane wave which gets refracted at an interface between two different media, 1 and 2. Shown are the wave-fronts (a group of parallel planes in which all the points oscillate in phase) separated by the wavelength in the medium 1. Which among the drawings below illustrating the wave fronts propagation in the medium 2 is most compatible with refraction of this wave?





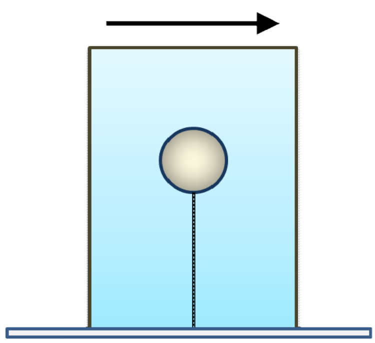
23. *(3 points)* Shown below is a graph of potential energy $U(x)$ as a function of position x for an object performing one-dimensional motion.



Total mechanical energy of the object is conserved to amount $E = 40$ mJ. Which of the following statements is NOT true in the range $0\ \mu\text{m} < x < 70\ \mu\text{m}$?

(A) The object comes to rest at position $x = 44\ \mu$m.
(B) The object gains the kinetic energy of 28 mJ at position $x = 50\ \mu$m.
(C) The motion of the object is confined within the range $20\ \mu\text{m} \le x \le 60\ \mu\text{m}$
(D) The maximum kinetic energy reached by the object amounts 32 mJ.
(E) The object comes to instantaneous rests at positions $x = 20\ \mu$m and $x = 60\ \mu$m.

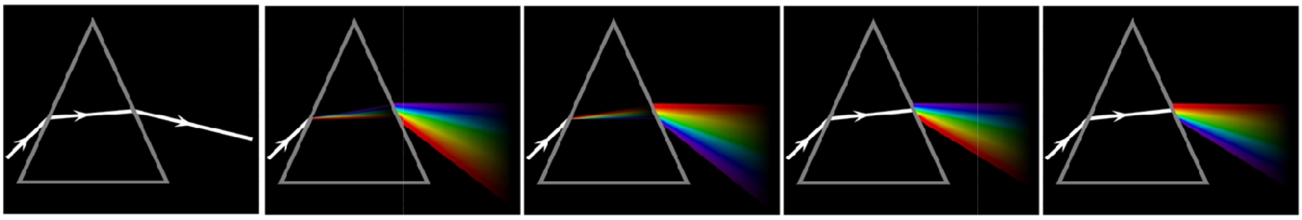
24. *(3 points)* A weighty ball, floating inside a closed cylindrical container entirely filled with the water, is vertically tied with the help of a massless inextensible thread to bottom of the container. The thread is fairly taut. The container moves horizontally on the ground to the right at a uniform speed, as is given in the figure (arrow's direction sense). All of the sudden, the container starts decelerating uniformly. What is going to happen with the ball right after?



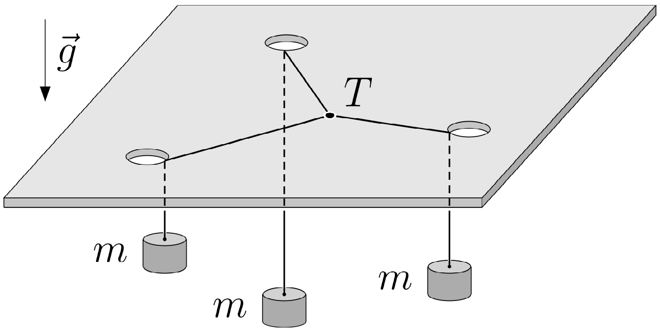
(A) The ball will start inclining to the right, i.e. in the arrow direction, keeping the thread taut.
(B) The ball will start inclining to the left, i.e. opposite to the arrow direction, keeping the thread taut.
(C) Nothing particular can be concluded - more information is required.
(D) Nothing is going to change - the ball will remain stationary, making the thread as taut as before.
(E) The ball will start falling down, making the thread loose.

25. *(4 points)* In Isaac Newton's experiment, an entirely solid prism in vacuum is illuminated with an incident ray of white (daily) light which enters it from the left. The entire body of the prism is made of a dispersive transparent material whose refractive index varies with vacuum wavelength of the white light constituent as, $n(\lambda) = 1.5 + C/\lambda^2$, where $C > 0$ stands for a constant expressed in nm^2. Which figure below correctly represents the refraction of the rays?

(A) **(B)** **(C)** **(D)** **(E)**



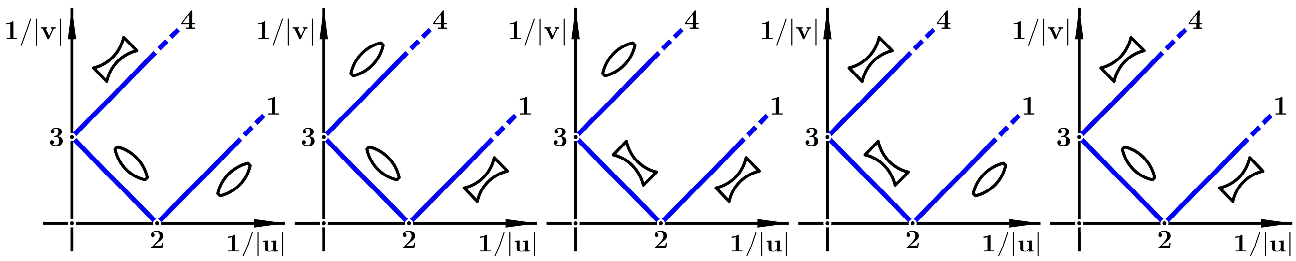
26. *(4 points)* A horizontal solid sheet is drilled three arbitrarily distributed holes which form the three vertices of a triangle. Three thin inextensible threads pass through the three holes, as is given in the figure. Three ends of the threads are knotted together (point T), and a hanging bob of mass m is attached to each of the other ends. If the three bobs reach the mechanical equilibrium, then the point T represents



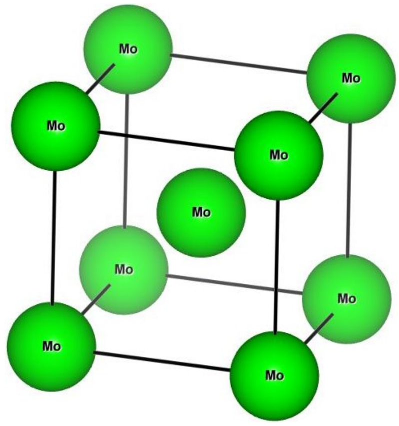
(A) Orthocenter - the intersection point of the three altitudes of the triangles
(B) Incenter - the centre of a circle inscribed in the triangle.
(C) Centroid - the centre of gravity of the triangle.
(D) Such a point that the sum of the distances from each of the three vertices of the triangle to the point T is the smallest possible.
(E) Circumcenter - the centre of a circumference circumscribed in the triangle.

27. *(4 points)* Consider two thin lenses, converging and diverging one, both made of the same transparent material and shaped with the identical spherical boundaries, either concave or convex. Let **u** and **v** be the object and image position (of algebraic numeric value in general) from the lens, respectively. In every graph below there are three characteristic straight lines (1-2, 2-3, 3-4), and each should feature a proper $1/|\mathbf{v}|$ *vs.* $1/|\mathbf{u}|$ dependence for a lens type indicated by the lens symbol closeby. Incidentally, out of the two considered lens types, there is exactly one lens symbol drawn near each line. Find the graph matching the $1/|\mathbf{v}|$ *vs.* $1/|\mathbf{u}|$ dependence with the correct arrangement of the lens type.

(A) **(B)** **(C)** **(D)** **(E)**

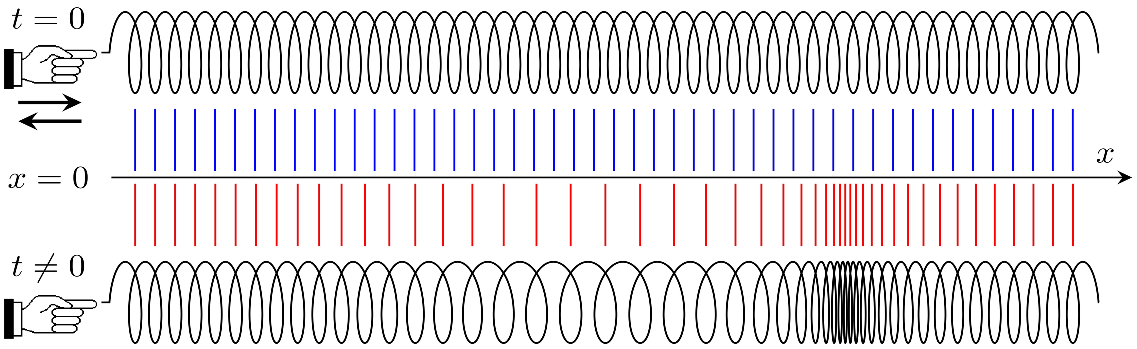


28. *(4 points)* Atom of Molybdenum (Mo) element can to some extent be considered as solid sphere of radius R and mass m. These atoms form a regular infinite arrangement (a crystalline lattice) such that its unit cell represents a cube of edge $4R/\sqrt{3}$. Periodical reappearance of such unit cells along all the three spatial directions leads to the crystalline lattice formation. Mo atoms populate the vertices of the cube, as well as its centre. See the figure. Mass density of the Molybdenum crystalline lattice is therefore:

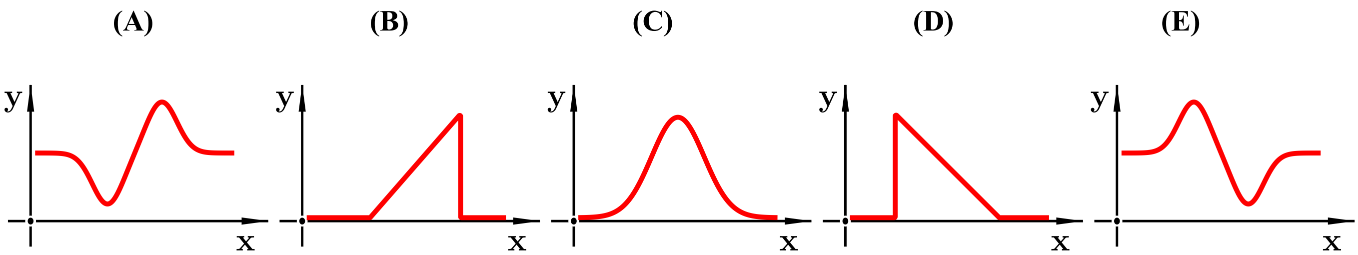


(A) $3m/4\pi R^3$
(B) $3\sqrt{3}m/16R^3$
(C) $27m/64R^3$
(D) $3m/2\pi R^3$
(E) $3\sqrt{3}m/32R^3$

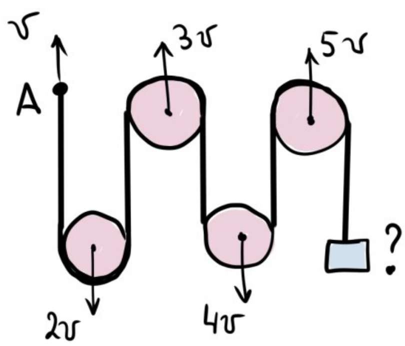
29. *(4 points)* Consider a long coil spring whose end is rapidly displaced back and forth by hand along x-axis, as is given in the upper subfigure ($t = 0$). Initially, the spring had all its coil positions undisturbed (blue lines, each y=0). As the left end of the spring is displaced to the right/left, each coil pushes on the next, displacing the coils one after the other to the right/left. The result is a longitudinal wave pulse propagating to the right, with each coil temporarily being displaced in the direction of propagation of the wave pulse. A snapshot of the propagating wave pulse along x-axis is given in the lower subfigure, at some instant ($t \neq 0$). The coil positions are now displaced (red lines), each by position y, which is measured with respect to the original undisturbed coil position (blue lines, each y=0) at point x. This results in a



displacement curve $y(x)$ for the longitudinal wave pulse propagating along the spring. Displacements to the right are assumed positive ($y > 0$). Which one of the following graphs most closely represents $y(x)$?

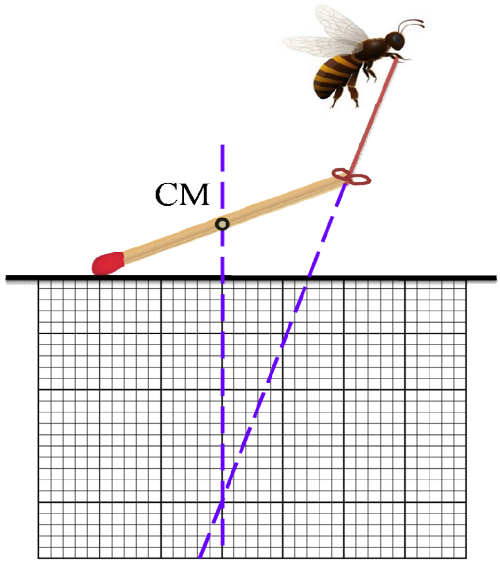


30. *(4 points)*. The figure shows a snapshot of a system of moving pulleys of negligible dimensions. It turns out that point A is pulled with velocity $v = 1$ cm/s, while instantaneously, velocities of the pulleys are $2v$, $3v$, $4v$, and $5v$, respectively. The thread is taut and inextensible. Within the accuracy to 1 cm/s, at what speed and in what direction will the weight move at the moment (upwards or downwards)?



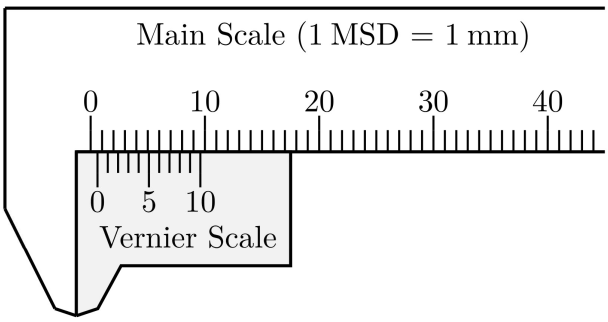
(A) 3 cm/s downwards
(B) 29 cm/s upwards
(C) 27 cm/s upwards
(D) 15 cm/s upwards
(E) 15 cm/s downwards

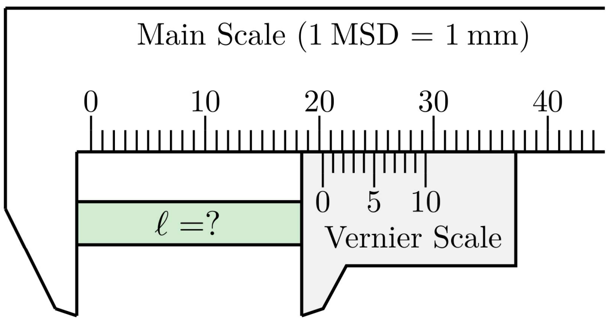
31. *(4 points)* A flying bee is pulling a weighty matchstick with the help of a light inextensible thread, as given in the sketch. At the instant shown, the matchstick is about to slide slowly on the horizontal floor. The matchstick is made of such a material that its centre of mass (CM) is as positioned as in the figure. You might benefit from the sketch assuming that the dimensions and distances in it are correct within an unknown scale factor. Some auxiliary dashed lines are shown in the diagram too, that you may find useful if needed. Estimate the coefficient of friction (kinetic=static) between the matchstick and the floor.



(A) 0.25
(B) 2.0
(C) 0.75
(D) 1.0
(E) 0.50

32. *(4 points)* The two lower figures illustrate a pair of Vernier callipers. Its two scale readings are singled out: fixed Main Scale (MS) and movable Vernier Scale (VS) of which Divisions (D) obey: 10 VSD = 9 MSD = 9 mm. The closed jaws of the pair of Vernier callipers, shown in the left subfigure, are in direct contact with each other. The same pair of Vernier callipers is used to measure the length ℓ of an object extending the jaws, as given in the right subfigure. Find the numeric value of ℓ.





(A) $\ell = 23.3$ mm **(B)** $\ell = 22.7$ mm **(C)** $\ell = 20.3$ mm **(D)** $\ell = 19.7$ mm **(E)** $\ell = 20.9$ mm

The end!