2023 Academic Challenge

PHYSICS EXAM – REGIONAL

Physics Test Production Team

Steven Daniels, Eastern Illinois University – Author/Team Leader
Jie Zou, Eastern Illinois University – Author
Don Pakey, Eastern Illinois University – Reviewer

GENERAL DIRECTIONS

Please read the following instructions carefully. This is a timed test; any instructions from the test supervisor should be followed promptly.

The test supervisor will give instructions for filling in any necessary information on the answer sheet. Most Academic Challenge sites will ask you to indicate your answer to each question by marking an oval that corresponds to the correct answer for that question. One oval should be marked to answer each question. Multiple ovals will automatically be graded as an incorrect answer.

Be sure ovals are marked as ● , not ⊙ , ◐ , ◑ , etc.

If you wish to change an answer, erase your first mark completely before marking your new choice.

You are advised to use your time effectively and to work as rapidly as you can without losing accuracy. Do not waste your time on questions that seem too difficult for you. Go on to the other questions, and then come back to the difficult ones later if time remains.

Time: 40 Minutes Number of Questions: 35

DO NOT OPEN TEST BOOKLET UNTIL YOU ARE TOLD TO DO SO!

Fundamental Constants

Quantity	Symbol	Value
Avogadro's number	N_A	6.022×10^{23}/mol
Boltzmann's constant	k	1.381×10^{-23} J/K
Electron charge magnitude	e	1.602×10^{-19} C
Permeability of free space	μ_0	$4\pi \times 10^{-7}$ T·m/A
Permittivity of free space	ϵ_0	8.854×10^{-12} C^2/(N·m^2)
Electrostatic Constant	$k = (4\pi\epsilon_0)^{-1}$	8.988×10^9 N·m^2/C^2
Planck's constant	h	6.626×10^{-34} J·s
Electron mass	m_e	9.1094×10^{-31} kg
Neutron mass	m_n	1.6749×10^{-27} kg
Proton mass	m_p	1.6726×10^{-27} kg
Speed of light in vacuum	c	2.9979×10^8 m/s
Universal gravitational constant	G	6.673×10^{-11} N·m^2/kg^2
Universal gas constant	R	8.3145 J/(mol·K)

Other information:

Acceleration due to gravity at Earth's surface: g = 9.80 m/s^2

0.00 ^{o}C = 273.15 K

Academic Challenge
Physics Test (Regional) – 2023

1. A microgram of Aluminum has a mass of

   a. 0.010 g b. 1.0×10^{-3} kg c. 1.0×10^{-6} kg d. 1.0×10^{-9} kg e. 1.0×10^{-12} kg

2. Given 3 vectors $\vec{A} = 3\hat{\mathbf{i}} + 2\hat{\mathbf{j}}$, $\vec{B} = -2\hat{\mathbf{i}} + 4\hat{\mathbf{j}}$, and $\vec{C} = 3.2$ at $134°$ counterclockwise from the *x* axis. What is the total vector $\vec{T} = \vec{A} - 2\vec{B} + \vec{C}$?

   a. 6.04 at 37.8˚ b. 10.6 at 345˚ c. 6.04 at 308˚ d. 6.04 at 322˚ e. 2.14 at 226˚

3. The density of copper is 8.96×10^3 kg/m^3. A 2.54 mm thick plate of copper is cut into squares that are 3.81 cm on a side. What is the mass of each square?

   a. 0.0330 g b. 33.0 g c. 86.7 g d. 330 g e. 867 g

4. The equation of motion of a particle is

$$x = -2.56t^2 + 2.2t + 2$$

   What is the instantaneous acceleration of the particle at time of 0.430 s?

   a. -5.12 m/s^2 b. -2.56 m/s^2 c. -1.28 m/s^2 d. 0.00 m/s^2 e. 1.28 m/s^2

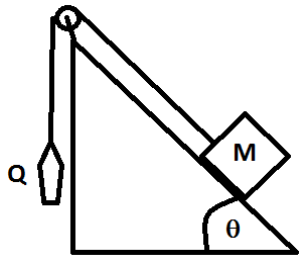
5. For the situation in problem 4 what is the instantaneous velocity of the particle at the time 1.00 s?

   a. -0.360 m/s b. -1.64 m/s c. -2.20 m/s d. -2.56 m/s e. -2.92 m/s

6. Sadie the cat has a mass of 3.46 kg. She gets on an elevator and there is a scale that measures weight in Newtons. As the elevator begins its decent it accelerates downward with a constant acceleration of 3.28 m/s^2. If Sadie steps onto the scale (with all four feet and no other contact) what is the reading of the scale?

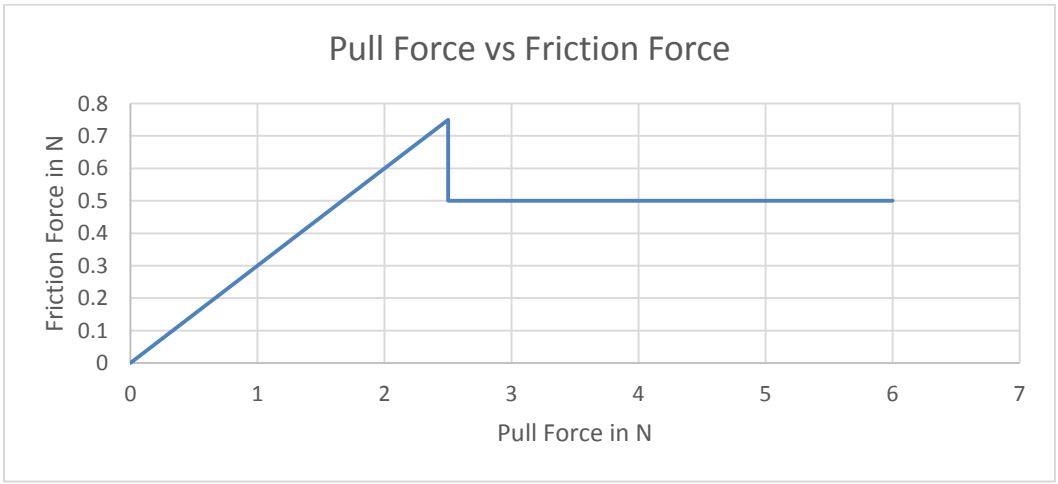
   a. 3.46 N b. 11.3 N c. 22.6 N d. 33.9 N e. 45.3 N

7. A block of mass M is connected to another block of mass Q as shown in the figure. The block is sliding up a rough incline with coefficient of kinetic friction of μ_k and the incline is at an angle θ as shown. The angle, mass of the blocks, and coefficient of friction are such that the block, M, slides up at constant velocity. What is a correct expression for the ratio of the masses (Q/M) for which this is true?



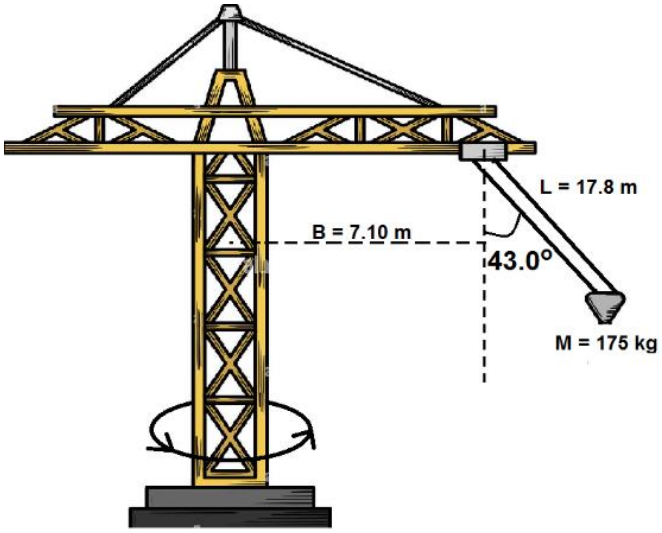
a. $\cos\theta + \mu_k \sin\theta$ b. $\frac{\tan\theta}{\{1+\mu_k\}}$ c. $\sin\theta + \mu_k \cos\theta$ d. $\frac{\sin\theta\cos\theta}{\{1-\mu_k\}}$ e. $\mu_k \tan\theta$

8. A 425 g block is on a horizontal surface. A pulling force is applied to the block in the +X direction. The magnitude of the pulling force increases in time. A graph of the pulling force vs the friction force is shown. What is the coefficient of static friction between the block and the horizontal surface?



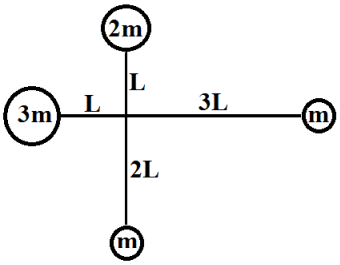
a. 0.120 b. 0.180 c. 0.300 d. 0.750
e. Insufficient information given in the problem to determine coefficient of static friction

9. A crane of the design shown in the sketch has a boom with cables connected to it a distance B from the center of rotation of the crane. The cables are a length L and hold up a mass of mass M. The crane is rotating about the central axis as shown. What is the angular velocity of the crane such that the cables make the angle with the vertical that is shown?



a. 0.606 rad/s b. 0.689 rad/s c. 0.868 rad/s d. 1.17 rad/s e. 2.15 rad/s

10. Consider the object in the figure. The masses can be considered point masses and the bars connecting them can be considered massless. The object rotates about an axis that is perpendicular to the paper and through the intersection of the two bars. Find the rotation rate if the rotational kinetic energy of the object is $\frac{54\ \mathrm{m\ L^2}}{T^2}$ where *T* is the period of revolution of the system.

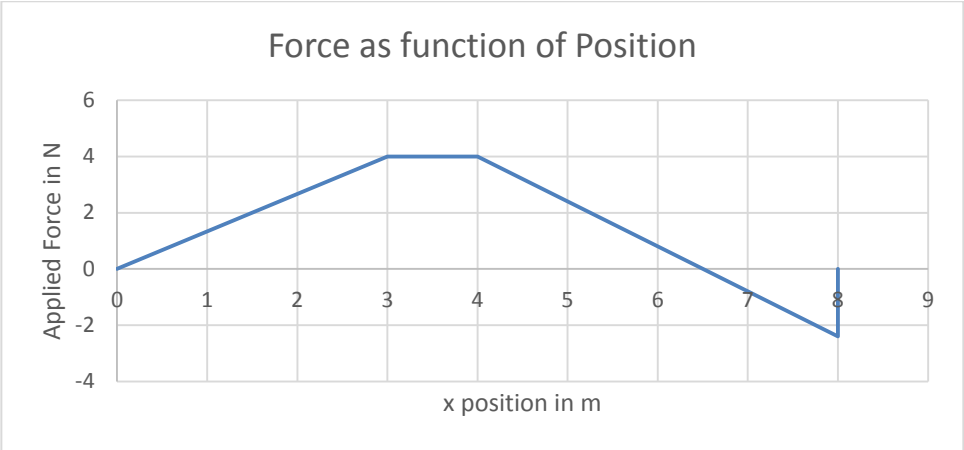


a. $\frac{1.73\ \mathrm{rad}}{T}$ b. $\frac{2.45\ \mathrm{rad}}{T}$ c. $\frac{3.29\ \mathrm{rad}}{T}$ d. $\frac{6.00\ \mathrm{rad}}{T}$ e. $\frac{6.28\ \mathrm{rad}}{T}$

11. An airliner jet engine can produce 3.22×10^5 N of thrust. The airliner, of mass 7.58×10^4 kg, is flying parallel to the ground at an altitude of 9.45 km and at a velocity of 273 m/s over a distance of 81.3 km. The engine is delivering the thrust to push the airliner in the direction that it is flying. What is the power that the engine is delivering to the airliner during this part of the flight?

a. 9.98×10^6 W b. 8.79×10^7 W c. 9.43×10^7 W
d. 2.03×10^8 W e. 7.02×10^9 W

12. A force is applied to a model train as it moves along a straight section of track. The force is applied parallel to the x axis as it moves along. The x component of the force varies with position as shown in the graph. What is the work done by the force during the motion from 0 m to 8.00 m on the x axis? (for clarification, the point (8.00 m, -2.40 N) is the right extremum)



a. -2.4 J b. 0.00 J c. 5.6 J d. 13.2 J e. 16.8 J

13. Consider a potential energy function that is only in the x direction and has the form

$$U(x) = 8 + 3x - 2x^2 + x^4$$

Where *x* is in meters and *U* is in Joules. What is the value of the force associated with this potential energy function at the point $x = 2.00$?

a. -27.0 N b. -23.1 N c. -22.0 N d. 22.0 N e. 27 N

14. If Galileo dropped a 6.50 kg mass from rest off of the Leaning Tower of Pisa from a height of 53.6 m above the ground, what would be the time it took the mass to reach the ground?

a. 3.31 s b. 3.44 s c. 5.47 s d. 8.99 s e. 10.9 s

15. As a continuation of the previous problem what would be the speed of the object that Galileo dropped as it passes the second floor that is 4.45 m above the ground?

a. 9.34 m/s b. 31.0 m/s c. 32.4 m/s d. 33.1 m/s e. 62.1 m/s

16. Two carts are on a level frictionless air track. They have ideal springs for bumpers. Cart 1 has a mass of 125 g and cart 2 has a mass of 147 g. The Cart 1 moves toward the right with a velocity of 1.78 m/s and cart 2 is moving toward Cart 1 with a velocity of –1.54 m/s. The two carts collide elastically at the point of their spring bumpers. What is the velocity of cart 1 after the collision?

a. 0.00 m/s b. -1.43×10^{-2} m/s c. –1.51 m/s d. –1.78 m/s –1.81 m/s

17. Three particles are located on the x axis at the points x, $\frac{3}{2}x$, and $\frac{7}{2}x$. Their masses are 2.00M, M, and 2.50M respectively. The particle at point x moves in the +y direction with a speed of v. At the same time the particle at the point $\frac{7}{2}x$ moves in the –y direction with a speed of $0.500v$. What is the y component of the velocity of the center of mass of the system?

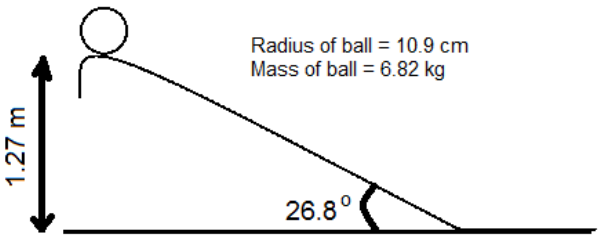
a. $\frac{3}{22}v$ b. $\frac{3}{11}v$ c. $\frac{3}{4}v$ d. $-\frac{25}{11}v$ e. $\frac{19}{8}v$

18. Information about G, e, ε_o, and m_e is given in the fundamental constants section at the beginning of this exam. What are the SI units of the quantity:

$$\frac{e^2 m_e}{4\pi\varepsilon_o G} \ ?$$

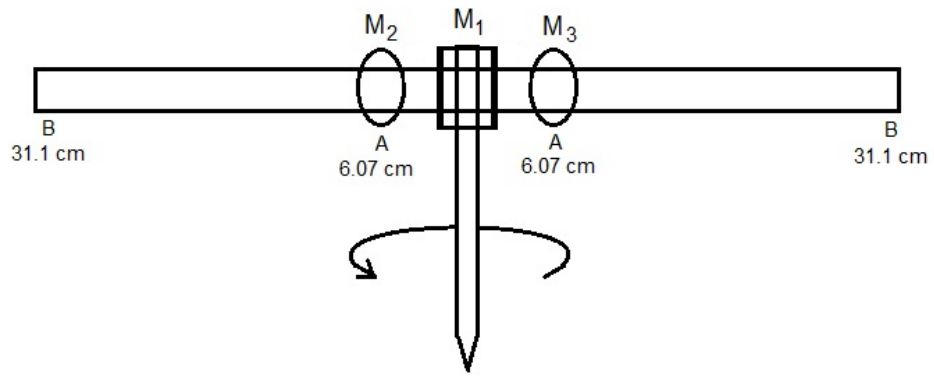
a. $\frac{\mathrm{C^4 kg^3}}{\mathrm{N^2 m^4}}$ b. $\frac{\mathrm{C^2}}{\mathrm{kg\ s}}$ c. $\frac{\mathrm{C^4\ kg\ s^3}}{\mathrm{m^4}}$ d. $\mathrm{kg^3}$ e. $\frac{\mathrm{kg\ m^2}}{\mathrm{C^2}}$

19. A ball return in a bowling alley raises a 6.82 kg bowling ball (of radius 10.9 cm) to the top of a 1.27 m ramp that is at an angle of 26.8° from the horizontal as shown in the figure. The ball rolls down the ramp without slipping. What is the linear speed of the ball when it leaves the bottom of the ramp? (the moment of inertia of a sphere about an axis through it's center is $I_{Sph} = \frac{2}{5}MR^2$)



a. 3.53 m/s b. 4.22 m/s c. 4.99 m/s d. 6.28 m/s e. 11.0 m/s

20. Consider three masses on a massless bar as shown in the figure. The bar is rotated about an axis through its center and perpendicular to the length of the bar. The rotation is frictionless. Masses are attached such that M_1 is 5.46 kg, $M_2 = M_3 = 1.87$ kg and can be considered point masses at the positions shown. There is an automatic release that can release the two equal masses and they will slide out on the bar from point A to point B (radii given in the figure). The release has no other effect on the bar. If the rotation starts as 18.3 rev/min before the release is triggered, what is the magnitude of the angular momentum of the system after the release is triggered and the equal masses move to point B on the bar?



a. $0.0132\ \text{kg}\frac{\text{m}}{\text{s}^2}$ b. $0.0264\ \text{kg}\frac{\text{m}}{\text{s}^2}$ c. $0.252\ \text{kg}\frac{\text{m}}{\text{s}^2}$ d. $0.347\ \text{kg}\frac{\text{m}}{\text{s}^2}$ e. $0.693\ \text{kg}\frac{\text{m}}{\text{s}^2}$

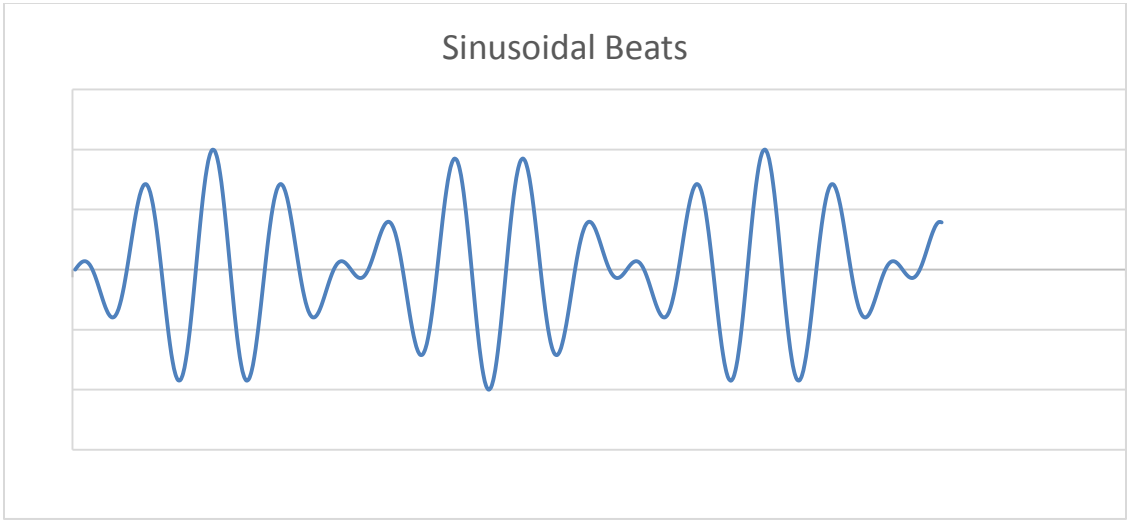
21. The world's first communications satellite was SCORE, launched by NASA in December 1958. If it were in a circular orbit (which it wasn't) with a period of 6.08×10^3 s (about 101 minutes), what altitude above the surface of the Earth would SCORE have orbited? (Mass of SCORE = 3980 kg, Mass of Earth = 5.97×10^{24} kg, Radius of Earth = 6.38×10^6 m)

a. 819 km b. 2800 km c. 6900 km d. 7200 km e. 9180 km

22. The graph shows a sinusoidal function that is of the form:

$$Y = A\{\sin \alpha X\} * [\cos \beta X]$$

In order to get this beat pattern which shows a possible relationship between α and β?



a. $\alpha = 3\beta$ b. $\alpha = \frac{\beta}{3}$ c. $\alpha = \frac{\beta}{2}$ d. $\alpha = \frac{\beta}{4}$ e. $\alpha = \frac{\beta}{8}$

23. Two liquids (oil and water) are placed in a U-shaped tube with a very thin membrane to separate them that goes across the tube. The membrane can move within the tube and the system is set so that the membrane rests at the center of the bottom of the U. The density of the water is greater than the density of the oil. The U is open at the top in both arms. Which of the following statements is true:

a. The water must go further up on it's side of the tube than the oil goes on it's side.
b. The oil must go further up on it's side of the tube than the water goes on it's side.
c. The tops of the oil and the water must be at the same height in the tube.
d. It is impossible arrange the membrane at the bottom center of the U (it will always be significantly off center)
e. there is not enough information given to draw any conclusions about the heights of the oil and the water.

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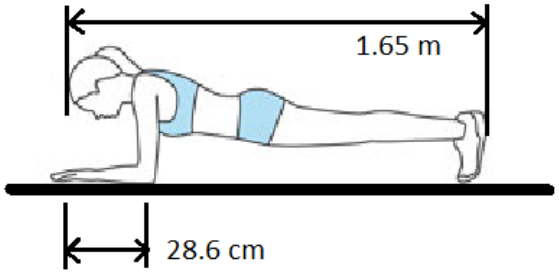
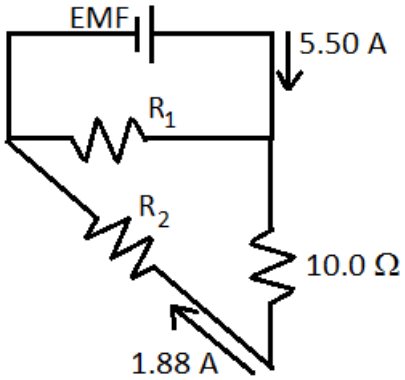
24. The planking trend is also considered good exercise. Consider the person supporting 63.0 kg of their mass on their elbows and toes as shown in the sketch.



The person measures 1.65 m tall. The toes can be considered one end of the plank. The elbows are 28.6 cm from the head as shown. The center of mass is at 0.983 m from the feet. Assume that the force on each elbow is the same and the force on each toe is the same. What is the force on each elbow? (also assume that the plank is horizontal)

a. 86.2 N b. 172 N c. 222 N d. 309 N e. 445 N

25. Consider the circuit shown. The resistor R_1 dissipates 200 W of electrical energy. Some currents and resistors are shown. What is the resistance of the resistor R_2?



a. 9.34 Ω b. 19.4 Ω c. 29.4 Ω d. 55.2 Ω e. 96.4 Ω

26. In Thermodynamics the term “heat” most closely means:

a. A description of a state of hotness or coldness.
b. The amount of energy contained in a body.
c. The amount of temperature change that is dependent on the specific material.
d. A measure of temperature that includes humidity and wind effects.
e. Energy in transit from one body to another because of temperature difference.

27. A ruler moving at relativistic speed passes you and you note that it is the same length at a dollar bill that you are holding. You measure your dollar bill to be 15.5 cm and, of course you know the ruler would be 0.305 m in its own reference frame. How fast was the ruler moving relative to you?

a. 0.508*c* b. 0.701*c* c. 0.742*c* d. 0.861*c* e. 0.927*c*

28. A magnetic field in a region of space is given by

$$\vec{B} = 0.0345\ \text{T}\,\hat{\mathbf{i}} + 0.0247\ \text{T}\,\hat{\mathbf{j}} + 0.159\ \text{T}\,\hat{\mathbf{k}}$$

What is the magnetic flux through the flat rectangular surface with corners at the origin, (50 cm, 0, 0), (0, 0, 20 cm), and (50 cm 0, 20 cm)?

a. 0.00247 Wb b. 0.0165 Wb c. 0.0492 Wb d. 0.0798 Wb e. 0.0864 Wb

29. An isotope of Europium, $^{152}\text{Eu}_{63}$ decays by β^+ decay. Here is a list of the elements nearby to Europium on the periodic chart:

Z	Element	Symbol	Atomic Mass
59	Praseodymium	Pr	140.91
60	Neodymium	Nd	144.24
61	Promethium	Pm	147
62	Samarium	Sm	150.36
63	Europium	Eu	151.96
64	Gadolinium	Gd	157.25
65	Terbium	Tb	158.93
66	Dysprosium	Dy	162.5
67	Holmium	Ho	164.93

What is the element that is the decay product of this reaction?

a. Praseodymium b. Promethium c. Samarium d. Europium e. Gadolinium

30. Consider a box, of mass m, sliding down an incline that makes an angle θ with the horizontal. The coefficient of friction is such that the speed of the box remains constant. What is the coefficient of friction in terms of the mass, g, and the angle of the incline?

a. $\tan\theta$ b.$\cot\theta$ c. $mg\cos\theta$ d. $mg\sin\theta$ e. $\dfrac{\cos\theta}{\cos\theta + \sin\theta}$

31. As a continuation of the previous problem a new coefficient of friction is generated. What is the new coefficient of friction if the acceleration of the box down the incline is 1.25 m/s^2?

a. $\dfrac{(g\sin\theta - g\cos\theta)}{\frac{5m}{4s^2}}$ b. $\sin\theta - \dfrac{\frac{4m}{5s^2}}{g\sin\theta}$ c. $\cos\theta - \dfrac{\frac{4m}{5s^2}}{g\sin\theta}$

d. $\cot\theta - \dfrac{\frac{5m}{4s^2}}{g}\csc\theta$ e. $\tan\theta - \dfrac{\frac{5m}{4s^2}}{g}\sec\theta$

32. How many photons of wavelength of ultraviolet light at a wavelength of 435 nm would it take to carry 435 ergs of energy?

a. 1.00×10^{9} b. 4.35×10^{9} c. 9.52×10^{13} d. 1.00×10^{16} e. 9.52×10^{20}

33. Consider a stopped organ pipe (closed at one end and open at the other end) that is making sound at 131 Hz (low C note). This sound it the 5^{th} harmonic for this tube. The speed of sound in air on this day is 343 m/s. What is the length of the stopped organ pipe?

a. 0.655 m b. 1.31 m c. 3.27 m d. 5.89 m e. 6.55 m

34. An electron with a mass of 9.11×10^{-31} kg is temporarily constrained to be within the indium nucleus. We will consider the nucleus to be an infinite 1 dimensional potential well of length 1.13×10^{-14}m. If the electron has an energy of 7.55×10^{-9}J, what is the value of the quantum number of this electron?

a. 1 b. 2 c. 4 d. 8 e. 16

35. A grasshopper with a mass of 1.16 g and jumping legs that can produce a constant force over their 1.42 cm kick produces enough power to jump many times further than humans can jump for their size. The jump will launch the grasshopper horizontally with a velocity of 2.15 m/s. What is the power produced by the grasshopper during the launch?

a. 0.000812W b. 0.00203W c. 0.203W d. 0.812W e. 2.03W