

Intermediate Exam Mastering Physics (3NAB0)

Date: January 22, 2014

Time: 9.00 - 12.00

This is a copy of the digital exam in Mastering Physics. The goal is to provide an overview of the exam. The complete exam including your specific numbers (and specific order of questions) is available at the website of Mastering Physics and is mandatory (verplicht). On your laptop the only application that is allowed to be opened, is your assessment in Mastering Physics. If you encounter serious problems at the website, you can use the included Correction Form. During the exam you are allowed to use SEPARATE from the laptop: (1) the printed formula pages from OASE; (2) (graphical) calculator; (3) dictionary.

Constants: acceleration due to gravity: $g = 9.80 \text{ m/s}^2$; latent heat of fusion of ice: $L_f = 3.34 \times 10^5 \text{ J/kg}$; bulk modulus for air: $B = 1.42 \times 10^5 \text{ Pa}$; speed of sound in air: $v = 344 \text{ m/s}$; sound reference intensity $I_0 = 1 \times 10^{-12} \text{ W/m}^2$

E1) Physicians use high-frequency ($f=1 \text{ MHz}$ to 5 MHz) sound waves, called ultrasound, to image internal organs. The speed of these ultrasound waves is ##m/s in muscle and ## m/s in air. We define the index of refraction of a material for sound waves to be the ratio of the speed of sound in air to the speed of sound in the material. Snell's law then applies to the refraction of sound waves.

- (1) At what angle from the normal does an ultrasound beam enter the heart if it leaves the lungs at an angle of ##° from the normal to the heart wall? (Assume that the speed of sound in the lungs is ## m/s .)

(2) What is the critical angle for sound waves in air incident on muscle?

IDENTIFY: Snell's law applies to the sound waves in the heart. (See Exercise 33.24.)

SET UP: $n_a \sin \theta_a = n_b \sin \theta_b$. If θ_a is the critical angle then $\theta_b = 90^\circ$. For air, $n_{\text{air}} = 1.00$. For heart

$$\text{muscle, } n_{\text{mus}} = \frac{344 \text{ m/s}}{1480 \text{ m/s}} = 0.2324.$$

EXECUTE: (a) $n_a \sin \theta_a = n_b \sin \theta_b$ gives $(1.00) \sin(9.73^\circ) = (0.2324) \sin \theta_b$. $\sin \theta_b = \frac{\sin(9.73^\circ)}{0.2324}$ so

$$\theta_b = 46.7^\circ.$$

(b) $(1.00) \sin \theta_{\text{crit}} = (0.2324) \sin 90^\circ$ gives $\theta_{\text{crit}} = 13.4^\circ$.

EVALUATE: To interpret a sonogram, it should be important to know the true direction of travel of the sound waves within muscle. This would require knowledge of the refractive index of the muscle.

E2) One suggested treatment for a person who has suffered a stroke is to immerse the patient in an ice-water bath at 0°C to lower the body temperature, which prevents damage to the brain. In one set of tests, patients were cooled until their internal temperature reached $##^\circ\text{C}$.

(3) To treat a $##\text{kg}$ patient, what is the minimum amount of ice (at 0°C) that you need in the bath so that its temperature remains at 0°C ? The specific heat capacity of the human body is $##\text{ J}/(\text{kg}^\circ\text{C})$, and recall that normal body temperature is 37.0°C .

IDENTIFY: The heat that comes out of the person goes into the ice-water bath and causes some of the ice to melt.

SET UP: Normal body temperature is $98.6^\circ\text{F} = 37.0^\circ\text{C}$, so for the person $\Delta T = -5^\circ\text{C}$. The ice-water bath stays at 0°C . A mass m of ice melts and $Q_{\text{ice}} = mL_f$. From Table 17.4, for water $L_f = 334 \times 10^3 \text{ J/kg}$.

EXECUTE: $Q_{\text{person}} = mc\Delta T = (70.0 \text{ kg})(3480 \text{ J/kg} \cdot ^\circ\text{C})(-5.0^\circ\text{C}) = -1.22 \times 10^6 \text{ J}$. Therefore, the amount of

heat that goes into the ice is $1.22 \times 10^6 \text{ J}$. $m_{\text{ice}}L_f = 1.22 \times 10^6 \text{ J}$ and $m_{\text{ice}} = \frac{1.22 \times 10^6 \text{ J}}{334 \times 10^3 \text{ J/kg}} = 3.7 \text{ kg}$.

EVALUATE: If less ice than this is used, all the ice melts and the temperature of the water in the bath rises above 0°C .

E3) For a person with normal hearing, the faintest sound that can be heard at a frequency of $##\text{Hz}$ has a pressure amplitude of about $##\text{Pa}$.

(4) Calculate the intensity of this sound wave at 20°C .

(5) Calculate the sound intensity level of this sound wave at 20°C .

(6) Calculate the displacement amplitude of this sound wave at 20°C .

IDENTIFY: Use Eq. (16.13) to relate I and p_{max} . $\beta = (10 \text{ dB})\log(I/I_0)$. Eq. (16.4) says the pressure amplitude and displacement amplitude are related by $p_{\text{max}} = BkA = B\left(\frac{2\pi f}{v}\right)A$.

SET UP: At 20°C the bulk modulus for air is $1.42 \times 10^5 \text{ Pa}$ and $v = 344 \text{ m/s}$. $I_0 = 1 \times 10^{-12} \text{ W/m}^2$.

EXECUTE: (a) $I = \frac{vp_{\text{max}}^2}{2B} = \frac{(344 \text{ m/s})(6.0 \times 10^{-5} \text{ Pa})^2}{2(1.42 \times 10^5 \text{ Pa})} = 4.4 \times 10^{-12} \text{ W/m}^2$

(b) $\beta = (10 \text{ dB})\log\left(\frac{4.4 \times 10^{-12} \text{ W/m}^2}{1 \times 10^{-12} \text{ W/m}^2}\right) = 6.4 \text{ dB}$

(c) $A = \frac{vp_{\text{max}}}{2\pi fB} = \frac{(344 \text{ m/s})(6.0 \times 10^{-5} \text{ Pa})}{2\pi(400 \text{ Hz})(1.42 \times 10^5 \text{ Pa})} = 5.8 \times 10^{-11} \text{ m}$

E4) The point of the needle of a sewing machine moves in Simple Harmonic Motion (SHM) along the x -axis with a frequency of ω Hz. At $t=0$ its position and velocity components are x_0 cm and v_{0x} cm/s.

(7) Find the acceleration component of the needle at $t=0$.

(8) Write an equation giving the position component of the point as a function of time.

(9) Write an equation giving the velocity component of the point as a function of time.

(10) Write an equation giving the acceleration component of the point as a function of time.

IDENTIFY: For SHM, $a_x = -\omega^2 x = -(2\pi f)^2 x$. Apply Eqs. (14.13), (14.15) and (14.16), with A and ϕ from Eqs. (14.18) and (14.19).

SET UP: $x = 1.1$ cm, $v_{0x} = -15$ cm/s. $\omega = 2\pi f$, with $f = 2.5$ Hz.

EXECUTE: (a) $a_x = -(2\pi(2.5 \text{ Hz}))^2 (1.1 \times 10^{-2} \text{ m}) = -2.71 \text{ m/s}^2$.

(b) From Eq. (14.19) the amplitude is 1.46 cm, and from Eq. (14.18) the phase angle is 0.715 rad. The angular frequency is $2\pi f = 15.7$ rad/s, so $x = (1.46 \text{ cm}) \cos((15.7 \text{ rad/s})t + 0.715 \text{ rad})$,

$v_x = (-22.9 \text{ cm/s}) \sin((15.7 \text{ rad/s})t + 0.715 \text{ rad})$ and $a_x = (-359 \text{ cm/s}^2) \cos((15.7 \text{ rad/s})t + 0.715 \text{ rad})$.

EVALUATE: We can verify that our equations for x , v_x and a_x give the specified values at $t = 0$.

E5) If the force on the tympanic membrane (eardrum) increases by about ΔF N above the force from atmospheric pressure, the membrane can be damaged.

(11) When you go scuba diving in the ocean, below what depth could damage to your eardrum start to occur? The eardrum is typically d mm in diameter. Take the density of seawater to be equal ρ kg/m³.

IDENTIFY: The external pressure on the eardrum increases with depth in the ocean. This increased pressure could damage the eardrum.

SET UP: The density of seawater is $1.03 \times 10^3 \text{ kg/m}^3$. The area of the eardrum is $A = \pi r^2$, with $r = 4.1$ mm. The pressure increase with depth is $\Delta p = \rho gh$ and $F = pA$.

EXECUTE: $\Delta F = (\Delta p)A = \rho ghA$. Solving for h gives

$$h = \frac{\Delta F}{\rho g A} = \frac{1.5 \text{ N}}{(1.03 \times 10^3 \text{ kg/m}^3)(9.80 \text{ m/s}^2)\pi(4.1 \times 10^{-3} \text{ m})^2} = 2.8 \text{ m}.$$

EVALUATE: 2.8 m is less than 10 ft, so it is probably a good idea to wear ear plugs if you scuba dive.

E6) Adult cheetahs, the fastest of the great cats, have a mass of about m kg and have been clocked at up to v mph (v m/s).

(12) How many joules of kinetic energy does such a swift cheetah have?

(13) By what factor would its kinetic energy change if its speed were doubled?

IDENTIFY: Find the kinetic energy of the cheetah knowing its mass and speed.

SET UP: Use $K = \frac{1}{2}mv^2$ to relate v and K .

EXECUTE: (a) $K = \frac{1}{2}mv^2 = \frac{1}{2}(70 \text{ kg})(32 \text{ m/s})^2 = 3.6 \times 10^4 \text{ J}$.

(b) K is proportional to v^2 , so K increases by a factor of 4 when v doubles.

EVALUATE: A running person, even with a mass of 70 kg, would have only 1/100 of the cheetah's kinetic energy since a person's top speed is only about 1/10 that of the cheetah.

E7) An average person can reach a maximum height of about ##cm when jumping straight up from a crouched position. During the jump itself, the person's body from the knees up typically rises a distance of around ##cm. To keep the calculations simple and yet get a reasonable result, assume that the *entire body* rises this much during the jump.

(14) With what initial speed does the person leave the ground to reach a height of ##cm ?

(15) In terms of this jumper's weight W , what force does the ground exert on him or her during the jump?

IDENTIFY: While the person is in contact with the ground, he is accelerating upward and experiences two forces: gravity downward and the upward force of the ground. Once he is in the air, only gravity acts on him so he accelerates downward. Newton's second law applies during the jump (and at all other times).

SET UP: Take $+y$ to be upward. After he leaves the ground the person travels upward 60 cm and his

acceleration is $g = 9.80 \text{ m/s}^2$, downward. His weight is w so his mass is w/g . $\Sigma F_y = ma_y$ and

$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0) \text{ apply to the jumper.}$$

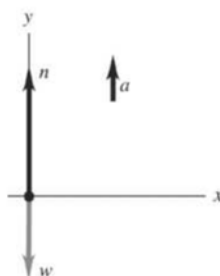
EXECUTE: (a) $v_y = 0$ (at the maximum height), $y - y_0 = 0.60 \text{ m}$, $a_y = -9.80 \text{ m/s}^2$.

$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0) \text{ gives } v_{0y} = \sqrt{-2a_y(y - y_0)} = \sqrt{-2(-9.80 \text{ m/s}^2)(0.60 \text{ m})} = 3.4 \text{ m/s.}$$

(c) For the jump, $v_{0y} = 0$, $v_y = 3.4 \text{ m/s}$ (from part (a)), and $y - y_0 = 0.50 \text{ m}$.

$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0) \text{ gives } a_y = \frac{v_y^2 - v_{0y}^2}{2(y - y_0)} = \frac{(3.4 \text{ m/s})^2 - 0}{2(0.50 \text{ m})} = 11.6 \text{ m/s}^2. \quad \Sigma F_y = ma_y \text{ gives } n - w = ma.$$

$$n = w + ma = w \left(1 + \frac{a}{g} \right) = 2.2w.$$



E8) The human body can survive a negative acceleration trauma incident (sudden stop) if the magnitude of the acceleration is less than ##m/s².

(16) If you are in an automobile accident with an initial speed of ## km/h and are stopped by an airbag that inflates from the dashboard, over what distance must the airbag stop you for you to survive the crash?

IDENTIFY: Assume that the acceleration is constant and apply the constant acceleration kinematic equations. Set $|a_x|$ equal to its maximum allowed value.

SET UP: Let $+x$ be the direction of the initial velocity of the car. $a_x = -250 \text{ m/s}^2$. $105 \text{ km/h} = 29.17 \text{ m/s}$.

EXECUTE: $v_{0x} = +29.17 \text{ m/s}$. $v_x = 0$. $v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$ gives

$$x - x_0 = \frac{v_x^2 - v_{0x}^2}{2a_x} = \frac{0 - (29.17 \text{ m/s})^2}{2(-250 \text{ m/s}^2)} = 1.70 \text{ m.}$$

EVALUATE: The car frame stops over a shorter distance and has a larger magnitude of acceleration. Part of your 1.70 m stopping distance is the stopping distance of the car and part is how far you move relative to the car while stopping.

E9) For its size, the common flea is one of the most accomplished jumpers in the animal world. A 2.1 mm-long, 0.50 mg critter (flea) can reach a height of 20 cm in a single leap.

(17) Neglecting air drag, what is the takeoff speed of such a flea?

(18) Calculate the kinetic energy of this flea at takeoff

(19) Calculate its kinetic energy per kilogram of mass.

IDENTIFY: The take-off kinetic energy of the flea goes into gravitational potential energy.

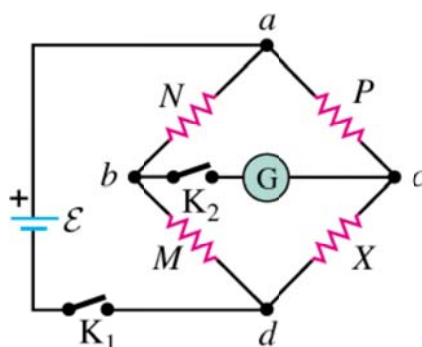
SET UP: Use $K_f + U_f = K_i + U_i$. Let $y_i = 0$ and $y_f = h$ and note that $U_i = 0$ while $K_f = 0$ at the maximum height. Consequently, conservation of energy becomes $mgh = \frac{1}{2}mv_i^2$.

EXECUTE: (a) $v_i = \sqrt{2gh} = \sqrt{2(9.80 \text{ m/s}^2)(0.20 \text{ m})} = 2.0 \text{ m/s}$.

(b) $K_i = mgh = (0.50 \times 10^{-6} \text{ kg})(9.80 \text{ m/s}^2)(0.20 \text{ m}) = 9.8 \times 10^{-7} \text{ J}$. The kinetic energy per kilogram is

$$\frac{K_i}{m} = \frac{9.8 \times 10^{-7} \text{ J}}{0.50 \times 10^{-6} \text{ kg}} = 2.0 \text{ J/kg}.$$

E10) The circuit shown in the figure below, called a Wheatstone bridge, is used to determine the value of an unknown resistor X by comparison with three resistors M, N, and P whose resistances can be varied. For each setting, the resistance of each resistor is precisely known. With switches K_1 and K_2 closed, these resistors are varied until the current in the galvanometer G is zero; the bridge is then said to be balanced.



(20) If the galvanometer G shows zero deflection when $M = 10 \Omega$, $N = 20 \Omega$, $P = 30 \Omega$, what is the unknown resistance?

IDENTIFY and SET UP: Zero current through the galvanometer means the current I_1 through N is also the current through M and the current I_2 through P is the same as the current through X . And it means that points b and c are at the same potential, so $I_1 N = I_2 P$.

EXECUTE: (a) The voltage between points a and d is \mathcal{E} , so $I_1 = \frac{\mathcal{E}}{N+M}$ and $I_2 = \frac{\mathcal{E}}{P+X}$. Using these

expressions in $I_1 N = I_2 P$ gives $\frac{\mathcal{E}}{N+M} N = \frac{\mathcal{E}}{P+X} P$. $N(P+X) = P(N+M)$. $NX = PM$ and

$$X = MP/N.$$

$$(b) X = \frac{MP}{N} = \frac{(850.0 \Omega)(33.48 \Omega)}{15.00 \Omega} = 1897 \Omega$$

E11) A steel ball with mass m is dropped from a height of h onto a horizontal steel slab. The ball rebounds to a height of h' .

(21) Calculate the impulse delivered to the ball during impact.

(22) If the ball is in contact with the slab for a time of Δt , find the average force on the ball during impact.

IDENTIFY: Use the heights to find v_{1y} and v_{2y} , the velocity of the ball just before and just after it strikes the slab. Then apply $J_y = F_y \Delta t = \Delta p_y$.

SET UP: Let $+y$ be downward.

EXECUTE: (a) $\frac{1}{2}mv^2 = mgh$ so $v = \pm\sqrt{2gh}$.

$$v_{1y} = +\sqrt{2(9.80 \text{ m/s}^2)(2.00 \text{ m})} = 6.26 \text{ m/s}. \quad v_{2y} = -\sqrt{2(9.80 \text{ m/s}^2)(1.60 \text{ m})} = -5.60 \text{ m/s}.$$

$$J_y = \Delta p_y = m(v_{2y} - v_{1y}) = (40.0 \times 10^{-3} \text{ kg})(-5.60 \text{ m/s} - 6.26 \text{ m/s}) = -0.474 \text{ kg} \cdot \text{m/s}.$$

The impulse is $0.474 \text{ kg} \cdot \text{m/s}$, upward.

$$(b) F_y = \frac{J_y}{\Delta t} = \frac{-0.474 \text{ kg} \cdot \text{m/s}}{2.00 \times 10^{-3} \text{ s}} = -237 \text{ N}. \text{ The average force on the ball is } 237 \text{ N, upward.}$$

E12) A river flows due south with a speed of v_r . A man steers a motorboat across the river; his velocity relative to the water is v_b due east. The river is w wide.

(23) What is the magnitude of his velocity relative to the earth?

(24) What is the direction of his velocity relative to the earth?

(25) How much time is required to cross the river?

(26) How far south of his starting point will he reach the opposite bank?

IDENTIFY: Relative velocity problem in two dimensions. His motion relative to the earth (time displacement) depends on his velocity relative to the earth so we must solve for this velocity.

(a) SET UP: View the motion from above.

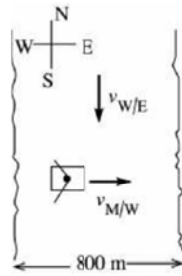


Figure 3.35a

The velocity vectors in the problem are:

$\vec{v}_{M/E}$, the velocity of the man relative to the earth

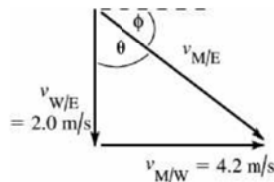
$\vec{v}_{W/E}$, the velocity of the water relative to the earth

$\vec{v}_{M/W}$, the velocity of the man relative to the water

The rule for adding these velocities is

$$\vec{v}_{M/E} = \vec{v}_{M/W} + \vec{v}_{W/E}$$

The problem tells us that $\vec{v}_{W/E}$ has magnitude 2.0 m/s and direction due south. It also tells us that $\vec{v}_{M/W}$ has magnitude 4.2 m/s and direction due east. The vector addition diagram is then as shown in Figure 3.35b.



This diagram shows the vector addition

$$\vec{v}_{M/E} = \vec{v}_{M/W} + \vec{v}_{W/E}$$

and also has $\vec{v}_{M/W}$ and $\vec{v}_{W/E}$ in their specified directions. Note that the vector diagram forms a right triangle.

Figure 3.35b

The Pythagorean theorem applied to the vector addition diagram gives $v_{M/E}^2 = v_{M/W}^2 + v_{W/E}^2$.

EXECUTE: $v_{M/E} = \sqrt{v_{M/W}^2 + v_{W/E}^2} = \sqrt{(4.2 \text{ m/s})^2 + (2.0 \text{ m/s})^2} = 4.7 \text{ m/s}$; $\tan \theta = \frac{v_{M/W}}{v_{W/E}} = \frac{4.2 \text{ m/s}}{2.0 \text{ m/s}} = 2.10$;

$\theta = 65^\circ$; or $\phi = 90^\circ - \theta = 25^\circ$. The velocity of the man relative to the earth has magnitude 4.7 m/s and direction 25° S of E.

(b) This requires careful thought. To cross the river the man must travel 800 m due east relative to the earth. The man's velocity relative to the earth is $\vec{v}_{M/E}$. But, from the vector addition diagram the eastward component of $v_{M/E}$ equals $v_{M/W} = 4.2 \text{ m/s}$.

Thus $t = \frac{x - x_0}{v_x} = \frac{800 \text{ m}}{4.2 \text{ m/s}} = 190 \text{ s}$.

(c) The southward component of $\vec{v}_{M/E}$ equals $v_{W/E} = 2.0 \text{ m/s}$. Therefore, in the 190 s it takes him to cross the river, the distance south the man travels relative to the earth is

$$y - y_0 = v_y t = (2.0 \text{ m/s})(190 \text{ s}) = 380 \text{ m}.$$