MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Physics

Physics 8.01 Spring 2005

WEEKLY QUIZ 5

Friday, March 4, 2005

FAMILY (LAST) NAME

GIVEN (FIRST) NAME

STUDENT ID NUMBER

Please check (✔) your class ☞

	L01	MTW 10:00	Walter Lewin
	L02	MTW 11:00	Walter Lewin
	L03	MTW 2:00	Min Chen
	L04	MTW 3:00	Min Chen

INSTRUCTIONS:

1. The FORMULA SHEET is in the back of this exam. You may tear it off. There is also an extra BLANK PAGE in case you need it.
2. This is a closed book exam. CALCULATORS, BOOKS, and NOTES are NOT ALLOWED.
3. Unless otherwise stated, to earn full credit you must show a valid DERIVATION and/or EXPLANATION of your answer, and you must express it in terms of the GIVEN VARIABLES.

Problem	**Maximum**	**Score**	**Grader**
1	40		
2	30		
3	30		
TOTAL	100		

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Problem 1: Work, work, work, ... (*40 points*)

In the following problems, you may assume that gravity acts downward with an acceleration which can be approximated as 10 m/s^2.

(a) (*3 points*) Tim lifts an 8 kg bag of groceries from the floor, and holds it at a height of 1 m above the floor. How much work was done on the bag by gravity?

(i) 0 J (ii) -80 erg (iii) 80 J (iv) 8.0 kJ (v) -80 J

(b) (*3 points*) How much work was done by Tim?

(i) 0 J (ii) -80 erg (iii) 80 J (iv) 8.0 kJ (v) -80 J

(c) (*3 points*) Tim holds the 8 kg bag stationary for 100 seconds. How much work has he done on the bag during this time?

(i) 0 J (ii) 8000 J (iii) 8000 N·s (iv) 800 J (v) 800 kJ (vi) -800 J

(d) (*3 points*) Tim walks 10 m, holding the bag at a constant height above the floor. How much work has he done on the bag?

(i) 0 J (ii) -800 erg (iii) 800 J (iv) 80 kJ (v) -800 J

(e) (*3 points*) A ball of mass 100 g is moving with a velocity $\vec{\mathbf{v}} = [2, 2, 2]$ m/s (or, equivalently $\vec{\mathbf{v}} = (2\hat{\imath} + 2\hat{\jmath} + 2\hat{k})$ m/s). What is its kinetic energy?

(i) 0 J (ii) 0.2 J (iii) 0.6 J (iv) 600 J (v) 200 J (vi) 600 erg

(f) (*3 points*) A particle moves under the influence of a force $\vec{\mathbf{F}} = [1, -2, 0]$ N (or equivalently $\vec{\mathbf{F}} = (\hat{\imath} - 2\hat{\jmath})$ N). It moves from the origin of the coordinate system to the point $(x, y, z) = (2, 1, 3)$ m. What is the work done by the force $\vec{\mathbf{F}}$ on the particle?

(i) 0 J (ii) 4 J (iii) -4 J (iv) $\sqrt{70}$ J (v) $-\sqrt{70}$ J
(vi) -1 J (vii) 1 J (viii) $\sqrt{15}$ J (ix) $-\sqrt{15}$ J

(g) (*3 points*) The same particle as in part (f), still moving under the influence of the same force $\vec{\mathbf{F}} = [1, -2, 0]$ N, is now moved from the point $(x, y, z) = (2, 1, 3)$ m to the point $(x, y, z) = (3, 2, 4)$ m. How much work is done by the force $\vec{\mathbf{F}}$ during this time period?

(i) 0 J (ii) 4 J (iii) -4 J (iv) $\sqrt{70}$ J (v) $-\sqrt{70}$ J
(vi) -1 J (vii) 1 J (viii) $\sqrt{15}$ J (ix) $-\sqrt{15}$ J

— *Problem 1 Continues* —

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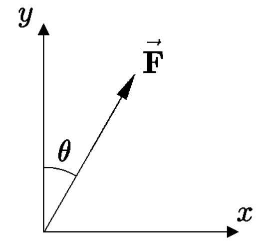
(h) (*3 points*) A particle moves along the x-axis a distance ℓ, while it is acted upon by a force of magnitude F, which acts in the x-y plane at an angle θ from the y-axis, as shown. What is the work done by the force on the particle?



(i) 0 (ii) $F\ell$ (iii) $F\ell\cos\theta$ (iv) $F\ell\sin\theta$ (v) $F\ell\cos^2\theta$

(i) (*3 points*) A particle moves along the y-axis of a coordinate system, with a force component $F_y = (2\ \mathrm{N/m^3})\, y^3$ acting on it. As the particle moves from the origin to $y = 3$ m, how much work is done on it by the force?

(i) 0 J (ii) 40.5 J (iii) -40.5 J (iv) 162 J (v) 81 J

(j) (*3 points*) A cannon ball of mass m is fired with an initial velocity $\vec{\mathbf{v}}_0 = v_{0,x}\hat{\boldsymbol{\imath}} + v_{0,y}\hat{\boldsymbol{\jmath}}$, which makes an angle $\theta = \arctan(v_{0,y}/v_{0,x})$ with respect to the horizontal. What is the kinetic energy of the cannon ball when it is at the peak (i.e., highest elevation) of its trajectory?

(i) 0 J (ii) $\frac{1}{2}mv_{0,y}^2\cos^2\theta$ (iii) $\frac{1}{2}mv_{0,x}^2\cos^2\theta$ (iv) $\frac{1}{2}mv_{0,y}^2$ (v) $\frac{1}{2}mv_{0,x}^2$

— *Problem 1 Continues* —

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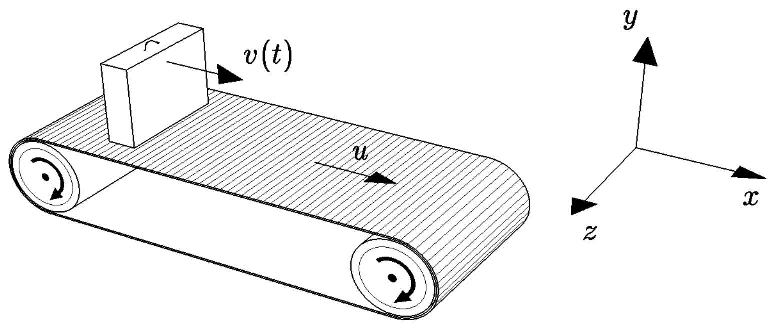

A suitcase of mass M is placed on a level conveyor belt at an airport. The coefficient of static friction between the suitcase and the conveyor belt is μ_s, and the coefficient of kinetic friction is μ_k, with $\mu_k < \mu_s$. The conveyor belt moves with constant speed u, and at time $t = 0$ the suitcase is placed on the conveyor with speed $v = 0$. At a time t_f, after moving a distance ℓ, the suitcase catches up with the conveyor belt, and starts to move at speed u with the conveyor belt. Gravity acts downward with acceleration $g > 0$. Work can depend on one's frame of reference, so be sure to answer the following three parts in the frame of reference of the airport.

(k) (*3 points*) How much work does gravity do on the suitcase, from $t = 0$ to $t = t_f$?

(i) 0 (ii) $\mu_k Mg$ (iii) $\frac{1}{2}Mu^2$ (iv) $-\frac{1}{2}Mu^2$ (v) $Mg\ell$ (vi) $\mu_s Mg\ell$

(l) (*3 points*) How much work does friction do on the suitcase during this period?

(i) 0 (ii) $\mu_k Mg$ (iii) $\frac{1}{2}Mu^2$ (iv) $-\frac{1}{2}Mu^2$ (v) $Mg\ell$ (vi) $\mu_s Mg\ell$

(m) (*4 points*) How much work does the force of friction from the suitcase do on the belt, during this time period?

(i) 0 (ii) $\mu_k Mg\ell$ (iii) $-\mu_k Mg\ell$ (iv) $\mu_k Mgut_f$ (v) $-\mu_k Mgut_f$

— *End of Problem 1* —

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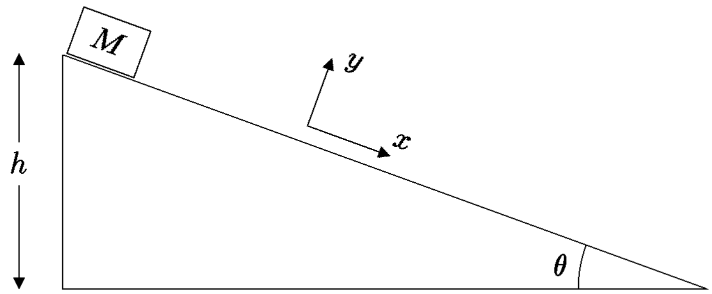
Problem 2: A block sliding on an inclined plane (*30 points*)



A block of mass M is placed on a plank of wood, oriented at an angle θ with respect to the horizontal, and the block then slides down until it meets the floor. The plank does not move. The initial height of the block is h, measured from the floor, and the size of the block is small compared to h. The coefficients of static and kinetic friction between the block and the plank are denoted by μ_s and μ_k, respectively. We will describe the system using the x-y coordinate system shown, with the x-axis oriented along the plane of the wood, and the y-axis oriented perpendicular to it. Assume that gravity acts downward, with acceleration $g > 0$. For the following questions, be careful that the answer you give has the correct sign.

(a) (*5 points*) As the block slides down the plank (from height h to height zero), how much work W_y is done on the block by the y-component of the gravitational force?

(b) (*5 points*) As the block slides down the plank, how much work W_x is done on the block by the x-component of the gravitational force?

(c) (*5 points*) As the block slides down the plank, how much work W_f is done on the block by friction?

(d) (*5 points*) As the block slides down the plank, how much work $W_{f,\text{plank}}$ is done by friction on the ***plank***?

(e) (*5 points*) As the block slides down the plank, how much work is done by the normal force acting on the block from the plank?

In addition to the forces of gravity and friction, there is an electrostatic force acting on the block. We are told that as the block slides down the plank, the electrostatic force does work W_{elec} on the block.

(f) (*5 points*) What is the speed of the block when it reaches the floor?

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Problem 3: A proton and a uranium nucleus (*30 points*)

A proton with mass m is propelled at an initial speed of v_0 directly towards a uranium nucleus from a distance x_0 away. The proton is repelled by the uranium nucleus with a force of magnitude $F = \alpha/x^2$, where x is the separation between the two objects and α is a positive constant. Assume that the uranium nucleus remains at rest. Do not assume that x_0 is large, so do not assume $1/x_0$ is negligible.

(a) (*10 points*) As the proton approaches the uranium nucleus, the repulsive force slows down the proton until it comes momentarily to rest, at a distance $x_{\min}$, after which the proton moves away from the uranium nucleus. What is this minimum separation $x_{\min}$?

(b) (*10 points*) Consider some separation x_1 in the range $x_{\min} < x_1 < x_0$. This is, x_1 represents a separation that is smaller than the initial separation between the proton and uranium nucleus, but still large enough so that it is reached during the subsequent motion of the proton. What is the speed of the proton when it is at a distance x_1 from the nucleus?

(c) (*10 points*) What is the speed of the proton when it is again a distance x_0 from the uranium nucleus?

— *End of Quiz* —

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QUIZ 5
FORMULA SHEET
Quiz Date: Friday, March 4, 2005

For motion in one dimension:

$$v_{\rm av} = \frac{\Delta x}{\Delta t} \qquad \text{Average velocity;}$$

$$v = \frac{{\rm d}x}{{\rm d}t} \qquad \text{Instantaneous velocity;}$$

For motion in three dimensions:

$$\vec{\mathbf{v}} = \frac{{\rm d}\vec{\mathbf{r}}}{{\rm d}t}\,; \qquad \vec{\mathbf{a}} = \frac{{\rm d}\vec{\mathbf{v}}}{{\rm d}t} = \frac{{\rm d}^2\vec{\mathbf{r}}}{{\rm d}t^2}\,; \qquad \vec{\mathbf{r}}(t_1) = \vec{\mathbf{r}}_0 + \int_0^{t_1} \vec{\mathbf{v}}\,{\rm d}t\,; \qquad \vec{\mathbf{v}}(t_1) = \vec{\mathbf{v}}_0 + \int_0^{t_1} \vec{\mathbf{a}}\,{\rm d}t\ .$$

For *constant* acceleration $\vec{\mathbf{a}}$, if $\vec{\mathbf{r}} = \vec{\mathbf{r}}_0$ and $\vec{\mathbf{v}} = \vec{\mathbf{v}}_0$ at time $t = 0$, then

$$\vec{\mathbf{v}}(t) = \vec{\mathbf{v}}_0 + \vec{\mathbf{a}}t$$

$$\vec{\mathbf{r}}(t) = \vec{\mathbf{r}}_0 + \vec{\mathbf{v}}_0 t + \frac{1}{2}\vec{\mathbf{a}}t^2\ .$$

For one-dimensional motion with constant acceleration a:

$$v^2 = v_0^2 + 2a(x - x_0)\ .$$

For circular motion at constant speed v:

$$a = \frac{v^2}{r}\ ,$$

where r is the radius of the circle, and the acceleration is directed towards the center of the circle.

If an object has position $\vec{\mathbf{r}}$ and velocity $\vec{\mathbf{v}}$, its position and velocity relative to an observer with position $\vec{\mathbf{r}}_0$ and velocity $\vec{\mathbf{v}}_0$ are given respectively by

$$\vec{\mathbf{r}}' = \vec{\mathbf{r}} - \vec{\mathbf{r}}_0\ , \qquad \vec{\mathbf{v}}' = \vec{\mathbf{v}} - \vec{\mathbf{v}}_0\ .$$

Average velocity and acceleration are given by

$$\vec{\mathbf{v}}_{\rm average} = \frac{\Delta\vec{\mathbf{r}}}{\Delta t}\ , \qquad \vec{\mathbf{a}}_{\rm average} = \frac{\Delta\vec{\mathbf{v}}}{\Delta t}\ .$$

Mass, Acceleration, and Force:

$$\vec{\mathbf{F}} = m\vec{\mathbf{a}} \qquad \text{(Newton's second law);}$$

$$\vec{\mathbf{F}} = -\frac{GMm}{r^2}\hat{\boldsymbol{r}} \qquad \text{(the gravitational force between two particles);}$$

$$\vec{\mathbf{F}} = \frac{1}{4\pi\epsilon_0}\frac{Qq}{r^2}\hat{\boldsymbol{r}} \qquad \text{(the electrostatic force between two particles);}$$

$$F_x = -kx \qquad \text{(Hooke's law);}$$

where $\hat{\boldsymbol{r}}$ is a unit vector pointing from the particle which is the source of the force, toward the particle on which the force is acting.

Friction:

$$\left|\vec{\mathbf{F}}_k\right| = \mu_k \left|\vec{\mathbf{N}}\right| \qquad \text{(kinetic friction);}$$

$$\left|\vec{\mathbf{F}}_s\right| \leq \mu_s \left|\vec{\mathbf{N}}\right| \qquad \text{(static friction).}$$

Kinetic Energy and Work:

1 Dimension	**3 Dimensions**	**Description**
$W \equiv F\Delta x$	$W \equiv \vec{\mathbf{F}} \cdot \overrightarrow{\mathbf{\Delta r}}$	Work done by a constant force $\vec{\mathbf{F}}$
$W \equiv \int F(x)\,\mathrm{d}x$	$W \equiv \int_{\vec{\mathbf{r}}_1}^{\vec{\mathbf{r}}_2} \vec{\mathbf{F}} \cdot \overrightarrow{\mathbf{dr}}$	Work done by a varying force $\vec{\mathbf{F}}$

$$\vec{\mathbf{a}} \cdot \vec{\mathbf{b}} = |\vec{\mathbf{a}}||\vec{\mathbf{b}}|\cos\theta \qquad \text{(scalar (or dot) product of two vectors);}$$

$$= a_x b_x + a_y b_y + a_z b_z$$

$$E_k = \frac{1}{2}mv^2 \qquad \text{(kinetic energy of a particle);}$$

$$W = E_{k,f} - E_{k,i} \qquad \text{(work-energy theorem);}$$

$$W = \frac{1}{2}kx^2 \qquad \text{(work to compress a spring);}$$

$$W = mgh \qquad \text{(work to lift a body near the surface of the Earth).}$$