PHYS 1443 – Section 002
Lecture #11

Wednesday, Oct. 8, 2008
Dr. Jaehoon Yu

- Free Fall Acceleration
- Kepler's Laws
- Motion in Accelerated Frames
- Work done by a Constant Force
- Work done by a Varying Force
- Work and Kinetic Energy Theorem

Announcements

- Reading assignments
  - CH. 6-6, 6-7 and 6-8
- Quiz next Monday, Oct. 13
  - Beginning of the class
  - Covers Ch. 4 – 6
- 2nd term exam on Wednesday, Oct. 22
  - Covers from Ch. 1 to what we cover up to Monday, Oct. 20
  - Time: 1 – 2:20pm in class
  - Location: SH103

Reminder: Special Project

- Derive the formula for the gravitational acceleration (g_{in}) at the radius $R_{in}\left(< R_E\right)$ from the center, inside of the Earth. (10 points)
- Compute the fractional magnitude of the gravitational acceleration 1km and 500km inside the surface of the Earth with respect to that on the surface. (6 points, 3 points each)
- Due at the beginning of the class Wednesday, Oct. 15

Special Project

- Two protons are separated by 1m.
  - Compute the gravitational force (F_G) between the two protons (3 points)
  - Compute the electric force (F_E) between the two protons (3 points)
  - Compute the ratio of FG/FE (3 points) and explain what this tells you (1 point)
- Due: Beginning of the class, Wednesday. Oct. 15

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Clathrate Materials: Novel Crystalline Phases of the Group IV Elements

Dr. Charley Myles
Texas Tech University

Wednesday, October 8, 2008 at 4:00 pm in Room 101 SH

Abstract

It is well-known that the ground state crystalline phase of each of the Group IV elements Si, Ge, and Sn is the diamond lattice. Less well-known is the fact that these elements can also form novel crystalline solids, called clathrates because of structural similarities to the clathrate hydrates. Their clathrate phases are metastable, expanded volume phases these elements. As in the diamond structure, in the clathrates, the atoms are tetrahedrally coordinated in sp^3 covalent bonding configurations with their near-neighbors. However, in contrast to the diamond lattice, the clathrates contain pentagonal rings of atoms and their lattices are open frameworks containing large (20-, 24-, 28-atom) "cages". There are two common varieties of clathrates: Type I, a simple cubic lattice with 46 atoms per unit cell and Type II, a face centered cubic lattice with 34 atoms per unit cell (136 atoms per cubic cell).

The clathrate cages can contain weakly bound impurities or "guests", usually Group I or Group II atoms. One reason these materials are interesting is that the choice of guest may be used to tune the material properties. The guests act as electronic donors, but because of their weak bonding, they have only small effects on the host electronic band structures. However, they can low frequency vibrational ("***rattling***") modes which can strongly affect the vibrational properties. Some laboratory-synthesized, guest-containing clathrates have been shown to be excellent candidates for thermoelectric applications ***precisely because*** the guests only weakly perturb the electronic properties, while strongly affecting the vibrational (heat transport) properties.

In this presentation, the clathrates and their lattice structures will be introduced and discussed. The results of calculations of the properties of some Si, Ge and Sn-based Type I and Type II clathrates will then be presented. Where possible, some of these results will be compared with experiment. The calculations were carried out using a density-functional based, planewave, pseudopotential method, and the results include equations of state, structural parameters, electronic band structures, vibrational spectra, isotropic mean-square atomic displacement amplitudes, and thermodynamic properties. Some recent results obtained in collaboration with my former student Koushik Biswas (now at NREL, Golden, CO) and with my current student Emmanuel Nenghabi will be included in this discussion

Refreshments will be served in the Physics Lounge at 3:30 pm

Newton's Law of Universal Gravitation

People have been very curious about the stars in the sky, making observations for a long time. The data people collected, however, have not been explained until Newton has discovered the law of gravitation.

Every particle in the Universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

How would you write this law mathematically?

$$F_g \propto \frac{m_1 m_2}{r_{12}^2}$$

With G

$$F_g = G \frac{m_1 m_2}{r_{12}^2}$$

G is the universal gravitational constant, and its value is

$$G = 6.673 \times 10^{-11}$$

Unit? $N \cdot m^2 / kg^2$

This constant is not given by the theory but must be measured by experiments.

This form of forces is known as the inverse-square law, because the magnitude of the force is inversely proportional to the square of the distances between the objects.

Free Fall Acceleration & Gravitational Force

Weight of an object with mass m is mg. Using the force exerting on a particle of mass m on the surface of the Earth, one can obtain

$$mg = G\frac{M_E m}{R_E^2}$$

$$g = G\frac{M_E}{R_E^2}$$

What would the gravitational acceleration be if the object is at an altitude h above the surface of the Earth?

$$F_g = mg' = G\frac{M_E m}{r^2} = G\frac{M_E m}{(R_E + h)^2}$$

$$g' = G\frac{M_E}{(R_E + h)^2}$$

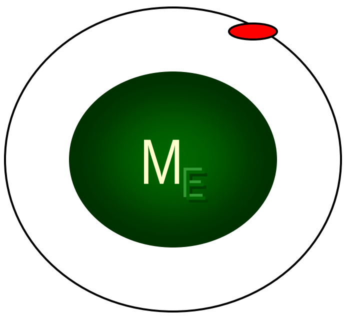
Distance from the center of the Earth to the object at the altitude h.

What do these tell us about the gravitational acceleration?

- The gravitational acceleration is independent of the mass of the object
- The gravitational acceleration decreases as the altitude increases
- If the distance from the surface of the Earth gets infinitely large, the weight of the object approaches 0.

Example for Gravitational Force

The international space station is designed to operate at an altitude of 350km. When completed, it will have a weight (measured on the surface of the Earth) of $4.22\mathrm{x}10^6$N. What is its weight when in its orbit?



The total weight of the station on the surface of the Earth is

$$F_{GE} = mg = G\frac{M_E m}{R_E^{\;2}} = 4.22\times 10^6\, N$$

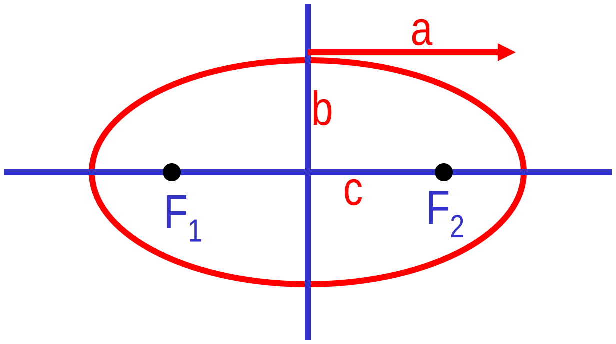
Since the orbit is at 350km above the surface of the Earth, the gravitational force at that altitude is

$$F_O = mg' = G\frac{M_E m}{\left(R_E + h\right)^2} = \frac{R_E^2}{\left(R_E + h\right)^2} F_{GE}$$

Therefore the weight in the orbit is

$$F_O = \frac{R_E^2}{\left(R_E + h\right)^2} F_{GE} = \frac{\left(6.37\times 10^6\right)^2}{\left(6.37\times 10^6 + 3.50\times 10^5\right)^2}\times 4.22\times 10^6 = 3.80\times 10^6\, N$$

Kepler's Laws & Ellipse



Ellipses have two different axis, major (long) and minor (short) axis, and two focal points, F_1 & F_2

a is the length of the semi-major axis

b is the length of the semi-minor axis

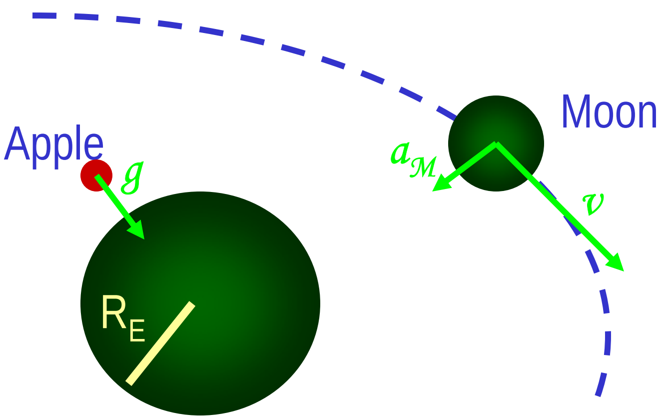
Kepler lived in Germany and discovered the law's governing planets' movements some 70 years before Newton, by analyzing data.

1. All planets move in elliptical orbits with the Sun at one focal point.
2. The radius vector drawn from the Sun to a planet sweeps out equal area in equal time intervals. (*Angular momentum conservation*)
3. The square of the orbital period of any planet is proportional to the cube of the semi-major axis of the elliptical orbit.

Newton's laws explain the cause of the above laws. Kepler's third law is a direct consequence of the law of gravitation being inverse square law.

The Law of Gravity and Motions of Planets

- Newton assumed that the law of gravitation applies the same whether it is to the apple or to the Moon.
- The interacting bodies are assumed to be point like particles.



Newton predicted that the ratio of the Moon's acceleration $a_{\mathcal{M}}$ to the apple's acceleration g would be

$$\frac{a_M}{g} = \frac{(1/r_M)^2}{(1/R_E)^2} = \left(\frac{R_E}{r_M}\right)^2 = \left(\frac{6.37\times10^6}{3.84\times10^8}\right)^2 = 2.75\times10^{-4}$$

Therefore the centripetal acceleration of the Moon, $a_{\mathcal{M}}$, is

$$a_M = 2.75\times10^{-4}\times9.80 = 2.70\times10^{-3}\,m/s^2$$

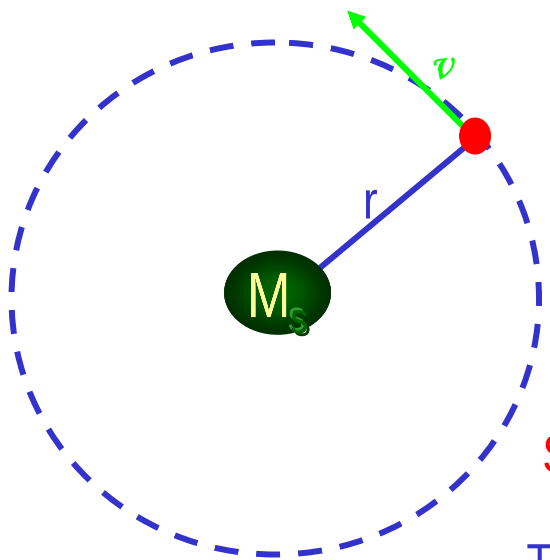
Newton also calculated the Moon's orbital acceleration $a_{\mathcal{M}}$ from the knowledge of its distance from the Earth and its orbital period, T=27.32 days=2.36×10^6s

$$a_M = \frac{v^2}{r_M} = \frac{(2\pi r_M/T)^2}{r_M} = \frac{4\pi^2 r_M}{T^2} = \frac{4\pi^2\times3.84\times10^8}{(2.36\times10^6)^2} = 2.72\times10^{-3}\,m/s^2 \approx \frac{9.80}{(60)^2}$$

This means that the distance to the Moon is about 60 times that of the Earth's radius, and its acceleration is reduced by the square of the ratio. This proves that the inverse square law is valid.

Kepler's Third Law

It is crucial to show that Keper's third law can be predicted from the inverse square law for circular orbits.



Since the gravitational force exerted by the Sun is radially directed toward the Sun to keep the planet on a near circular path, we can apply Newton's second law

$$\frac{GM_sM_P}{r^2} = \frac{M_p v^2}{r}$$

Since the orbital speed, v, of the planet with period T is $v = \frac{2\pi r}{T}$

The above can be written $\frac{GM_sM_P}{r^2} = \frac{M_p(2\pi r/T)^2}{r}$

Solving for T one can obtain $T^2 = \left(\frac{4\pi^2}{GM_s}\right)r^3 = K_s r^3$ and $K_s = \left(\frac{4\pi^2}{GM_s}\right) = 2.97\times10^{-19}\ s^2/m^3$

This is Kepler's third law. It's also valid for the ellipse with r as the length of the semi-major axis. The constant K_s is independent of mass of the planet.

Example of Kepler's Third Law

Calculate the mass of the Sun using the fact that the period of the Earth's orbit around the Sun is 3.16×10^{7}s, and its distance from the Sun is 1.496×10^{11}m.

Using Kepler's third law.

$$T^2 = \left(\frac{4\pi^2}{GM_s}\right) r^3 = K_s r^3$$

The mass of the Sun, M_s, is

$$M_s = \left(\frac{4\pi^2}{GT^2}\right) r^3$$

$$= \left(\frac{4\pi^2}{6.67 \times 10^{-11} \times \left(3.16 \times 10^{7}\right)^2}\right) \times \left(1.496 \times 10^{11}\right)^3$$

$$= 1.99 \times 10^{30}\, kg$$

Motion in Accelerated Frames

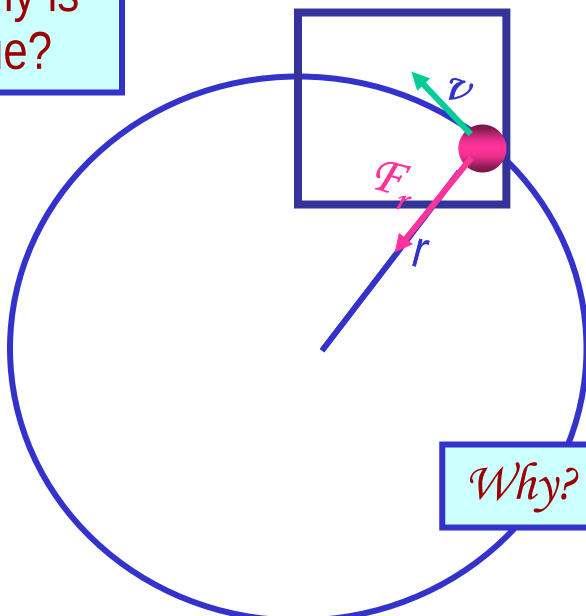
Newton's laws are valid only when observations are made in an inertial frame of reference. What happens in a non-inertial frame?

Fictitious forces are needed to apply Newton's second law in an accelerated frame.

This force does not exist when the observations are made in an inertial reference frame.

What does this mean and why is this true?

Let's consider a free ball inside a box under uniform circular motion.



How does this motion look like in an inertial frame (or frame outside a box)?

We see that the box has a radial force exerted on it but none on the ball directly

How does this motion look like in the box?

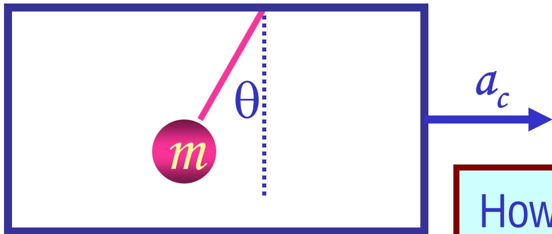
The ball is tumbled over to the wall of the box and feels that it is getting force that pushes it toward the wall.

Why?

According to Newton's first law, the ball wants to continue on its original movement but since the box is turning, the ball feels like it is being pushed toward the wall relative to everything else in the box.

Example of Motion in Accelerated Frames

A ball of mass m is hung by a cord to the ceiling of a boxcar that is moving with an acceleration *a*. What do the inertial observer at rest and the non-inertial observer traveling inside the car conclude? How do they differ?

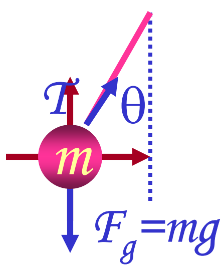


This is how the ball looks like no matter which frame you are in.

How do the free-body diagrams look for two frames?

How do the motions interpreted in these two frames? Any differences?

Inertial Frame



$$\sum \vec{F} = \vec{F}_g + \vec{T}$$

$$\sum F_x = ma_x = ma_c = T\sin\theta$$

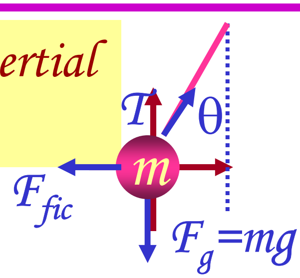
$$\sum F_y = T\cos\theta - mg = 0$$

$$T = \frac{mg}{\cos\theta}$$

$$a_c = g\tan\theta$$

For an inertial frame observer, the forces being exerted on the ball are only T and F_g. The acceleration of the ball is the same as that of the box car and is provided by the x component of the tension force.

Non-Inertial Frame



$$\sum \vec{F} = \vec{F}_g + \vec{T} + \vec{F}_{fic}$$

$$\sum F_x = T\sin\theta - F_{fic} = 0$$

$$F_{fic} = ma_{fic} = T\sin\theta$$

$$\sum F_y = T\cos\theta - mg = 0$$

$$T = \frac{mg}{\cos\theta}$$

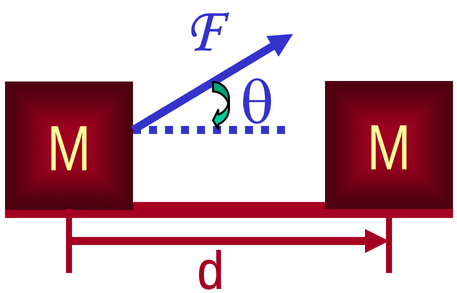
$$a_{fic} = g\tan\theta$$

In the non-inertial frame observer, the forces being exerted on the ball are T, F_g, and F_{fic}. For some reason the ball is under a force, F_{fic}, that provides acceleration to the ball.

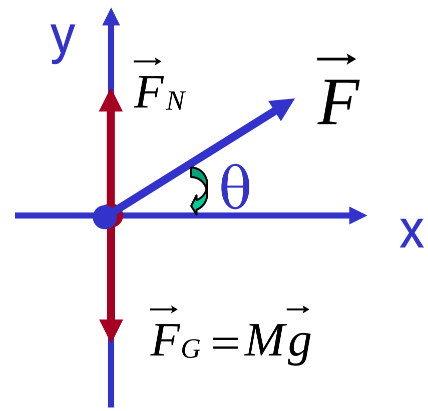
While the mathematical expression of the acceleration of the ball is identical to that of inertial frame observer's, the cause of the force is dramatically different.

Work Done by a Constant Force

A meaningful work in physics is done only when a sum of forces exerted on an object made a motion to the object.



Free Body Diagram



Which force did the work? Force $\vec{F}$ Why?

How much work did it do? $W = \left(\sum \vec{F}\right) \cdot \vec{d} = Fd\cos\theta$ Unit? $N \cdot m$ $= J$ (for Joule)

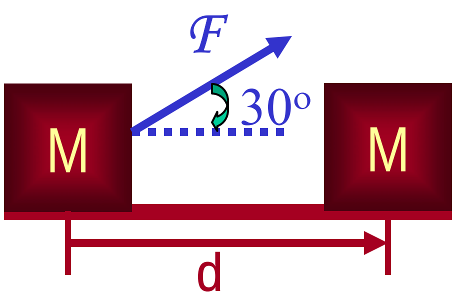
What does this mean?

Physical work is done only by the component of the force along the movement of the object.

Work is an energy transfer!!

Example of Work w/ Constant Force

A man cleaning a floor pulls a vacuum cleaner with a force of magnitude F=50.0N at an angle of 30.0° with East. Calculate the work done by the force on the vacuum cleaner as the vacuum cleaner is displaced by 3.00m to East.



$$W = \left(\sum \vec{F}\right)\cdot \vec{d} = \left|\left(\sum \vec{F}\right)\right|\left|\vec{d}\right|\cos\theta$$

$$W = 50.0 \times 3.00 \times \cos 30^{\circ} = 130 J$$

Does work depend on mass of the object being worked on?

Yes

Why don't I see the mass term in the work at all then?

It is reflected in the force. If an object has smaller mass, it would take less force to move it at the same acceleration than a heavier object. So it would take less work. Which makes perfect sense, doesn't it?

Scalar Product of Two Vectors

- Product of magnitude of the two vectors and the cosine of the angle between them $\vec{A}\cdot\vec{B} \equiv \left|\vec{A}\right|\left|\vec{B}\right|\cos\theta$
- Operation is commutative $\vec{A}\cdot\vec{B} = \left|\vec{A}\right|\left|\vec{B}\right|\cos\theta = \left|\vec{B}\right|\left|\vec{A}\right|\cos\theta = \vec{B}\cdot\vec{A}$
- Operation follows the distribution law of multiplication $\vec{A}\cdot\left(\vec{B}+\vec{C}\right) = \vec{A}\cdot\vec{B} + \vec{A}\cdot\vec{C}$
- Scalar products of Unit Vectors $\hat{i}\cdot\hat{i} = \hat{j}\cdot\hat{j} = \hat{k}\cdot\hat{k} = 1 \quad \hat{i}\cdot\hat{j} = \hat{j}\cdot\hat{k} = \hat{k}\cdot\hat{i} = 0$
- How does scalar product look in terms of components?

$$\vec{A} = A_x\hat{i} + A_y\hat{j} + A_z\hat{k} \qquad \vec{B} = B_x\hat{i} + B_y\hat{j} + B_z\hat{k}$$

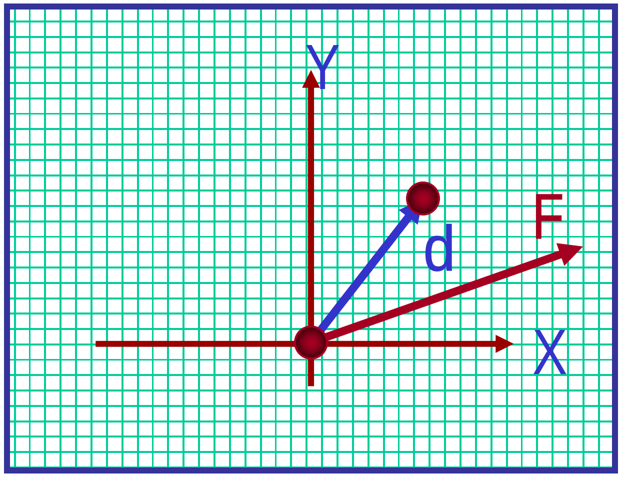
$$\vec{A}\cdot\vec{B} = \left(A_x\hat{i} + A_y\hat{j} + A_z\hat{k}\right)\cdot\left(B_x\hat{i} + B_y\hat{j} + B_z\hat{k}\right) = \left(A_xB_x\,\hat{i}\cdot\hat{i} + A_yB_y\,\hat{j}\cdot\hat{j} + A_zB_z\,\hat{k}\cdot\hat{k}\right) + cross\ terms$$

cross terms =0

$$\vec{A}\cdot\vec{B} = A_xB_x + A_yB_y + A_zB_z$$

Example of Work by Scalar Product

A particle moving on the xy plane undergoes a displacement **d**=(2.0**i**+3.0**j**)m as a constant force **F**=(5.0**i**+2.0**j**) N acts on the particle.



a) Calculate the magnitude of the displacement and that of the force.

$$\left|\vec{d}\right| = \sqrt{d_x^2 + d_y^2} = \sqrt{(2.0)^2 + (3.0)^2} = 3.6m$$

$$\left|\vec{F}\right| = \sqrt{F_x^2 + F_y^2} = \sqrt{(5.0)^2 + (2.0)^2} = 5.4N$$

b) Calculate the work done by the force F.

$$W = \vec{F} \cdot \vec{d} = \left(2.0\hat{i} + 3.0\hat{j}\right) \cdot \left(5.0\hat{i} + 2.0\hat{j}\right) = 2.0 \times 5.0\,\hat{i} \cdot \hat{i} + 3.0 \times 2.0\,\hat{j} \cdot \hat{j} = 10 + 6 = 16(J)$$

Can you do this using the magnitudes and the angle between **d** and **F**?

$$W = \vec{F} \cdot \vec{d} = \left|\vec{F}\right|\left|\vec{d}\right| \cos\theta$$