Physics 101H

General Physics 1 – Honors

Lecture 19 – 10/6/22

Energy conservation

Midterm 1

mean = 70%, median = 73%, standard deviation = 18%

A hard midterm! If you would like a very approximate estimate of what letter grade your result would correspond to, multiply your result by 80/70 ~ 1.14

However, this midterm is just one small component of your entire semester's work, so it does not mean that the result will be your letter grade for the course

Remember, the important thing is learning physics!

Grading on exams

You can improve your grade without solving all the problems!

I look for ways to give credit when you provide working or write down relevant information

I gave credit for (among other things):

- Drawing a diagram
- Writing down kinematic equations
- Attempting some reasonable algebra
- Writing down Newton's second law ($F_{net} = ma$)
- Attempting to resolve forces in perpendicular directions
- Writing down $a_c = v^2/r$
- Commenting on whether your result makes sense, or what you would expect if you had more time, or really any (correct) physics-related intuition or expectation

Always write (and draw) **something** for **every question**.

Summary

Topics

Friday: Work & energy [chapters 7/8]

- Work-energy theorem
- Potential energy

Yesterday: Computational physics and drag

Today: Energy conservation [chapter 8]

- Types of energy
- Energy transfer
- Energy conservation
- Power

Types of energy

Mechanical energy is the sum of the **kinetic** and **potential energy**

Types of potential energy

- Elastic potential energy
- Gravitational potential energy

Internal energy is energy stored within a system

- Heat energy, stored as kinetic and potential energy in atoms and molecules, corresponding to temperature
- Nonconservative forces typically turn work into internal (thermal) energy
- Discuss this in much more detail in PHYS 102(H)

Energy conservation

You may ask: “So what? Why all the fuss about energy?”

Answer: energy is **conserved**.

- Can’t make or destroy energy
- You can only move it around
- Or change its type

Example: Gravitational potential energy is turned into kinetic energy when you drop something. Along the way, friction turns that kinetic energy into thermal (internal) energy.

What types of energy transfer can we list?

Energy conservation

Mathematically

Closed system

No energy transfer to or from the system and its surroundings

Open system

Energy transfer to or from the system and its surroundings

Example: Neglecting air resistance, determine the speed of a dropped ball when it is a distance y above the ground.

Energy conservation*

*Not examinable

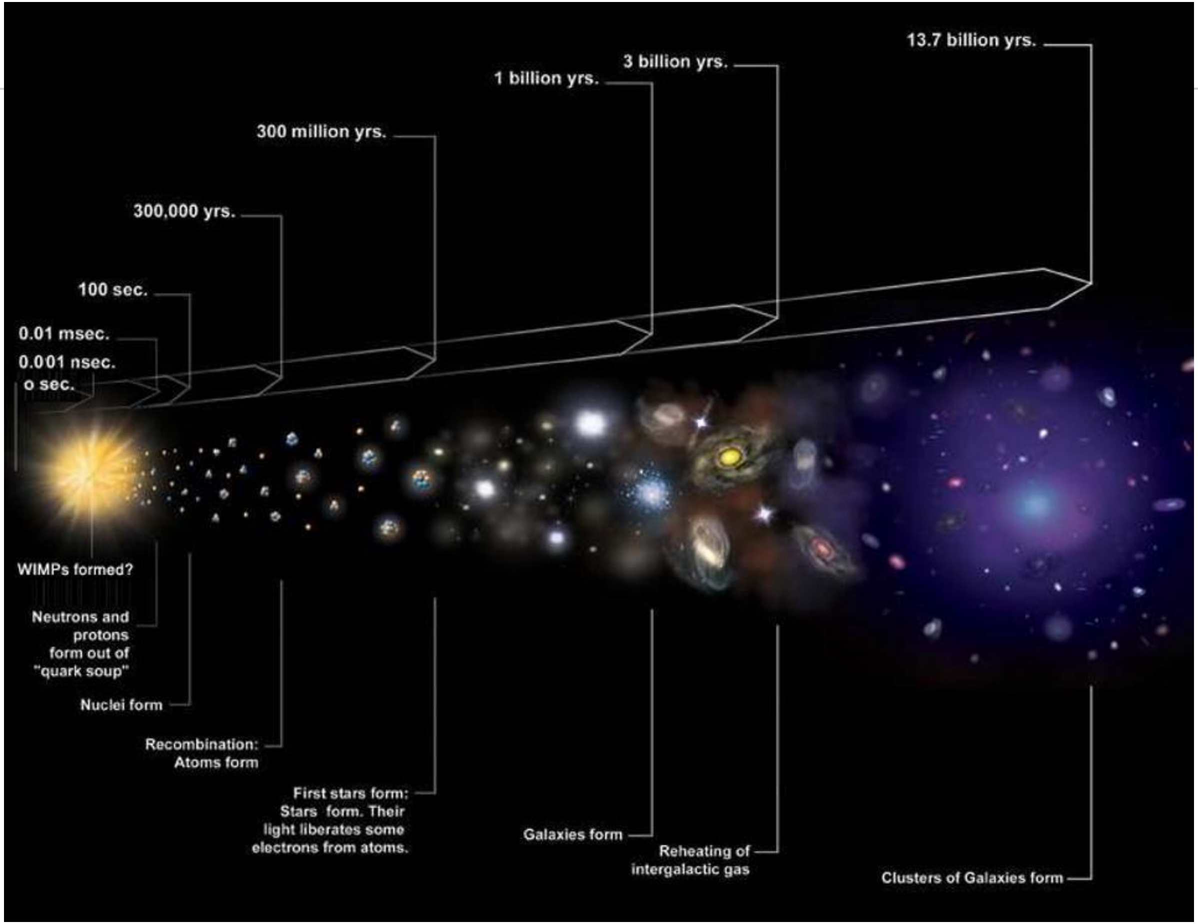
In fact, this is not the whole story (it rarely ever is…)

Defining energy conservation in the context of **general relativity** – the theory of gravity – is considerably more difficult, because spacetime itself carries energy density that contributes to the universe's **energy budget**

Further complicated by the **expansion of the universe**, because energy conservation ultimately arises from time-translation invariance

Energy conservation*

*Not examinable



Power

Power is the **rate of energy transfer**

Want more practice?

Try the following problems **Chapter 8** of the textbook:

- Conceptual questions: 1, 5, 9, 13, 17
- Potential energy: 21, 23, **73**
- Conservative and nonconservative force: 25, 27, 29, **85**
- Conservation of energy: 31, 35, 39, 53, 59, **77**

Answers are provided for questions with blue numbers (odd numbered)

Click on the number to be taken to the answer.

But make sure you at least **try** the problem first!

Summary

Topics

Yesterday: Computational physics & drag

- Air resistance (again)
- Python and Google Colab

Today: Energy conservation [chapter 8]

- Types of energy
- Energy transfer
- Energy conservation
- Power

Tomorrow: Momentum & collisions [chapter 9]

- Newton's third law and momentum
- Momentum and impulse
- Isolated systems
- Collisions

Extra example: Which is more work – lifting an object directly to a given height, or pushing it up a frictionless incline plane to the same height?

PHYSICS 101 - HONORS

Lecture 19 — 10/6/22

Energy transfer:
- work
- mechanical waves
- heat
- matter transfer
- electrical transmission
- electromagnetic radiation

Types of energy (slide 3)

$$E_{mech} = K + U = \frac{1}{2}mv^2 + U$$

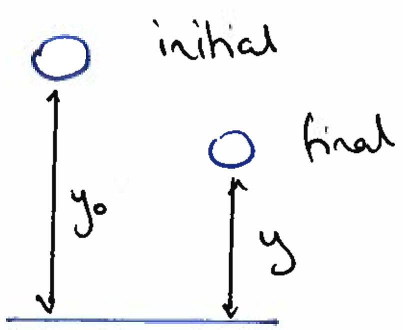
Elastic potential energy $U = \frac{1}{2}kx^2$

Gravitational potential energy $U = mgh$

Energy conservation $\Delta E = 0$

$\Delta E = \Delta K + \Delta U + \Delta E_{int}$

Speed example



Initial state

$$E_i = K_i + U_i + \cancel{E_{int,i}}^{\,0}$$
$$= \frac{1}{2}mv_i^2 + mgy_0$$

Final state

$$E_f = K_f + U_f + \cancel{E_{int,f}}^{\,0}$$
$$= \frac{1}{2}mv_f^2 + mgy$$

Energy conservation $\Rightarrow \Delta E = 0$

$\Rightarrow E_f - E_i = 0$

$\frac{1}{2}mv_f^2 + mgy - \frac{1}{2}mv_i^2 - mgy_0 = 0$

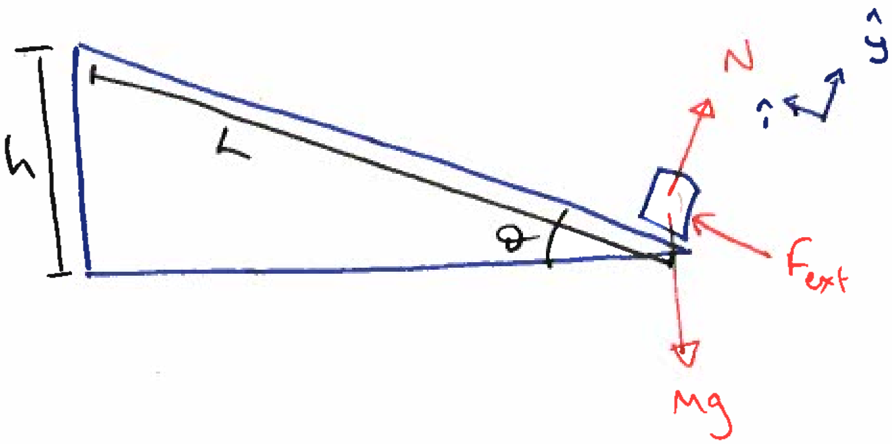
$\Rightarrow \frac{1}{2}m(v_f^2 - v_i^2) + mg(y - y_0) = 0$

$\frac{m}{2}(v_f^2 - v_i^2) = mg(y_0 - y)$

$\Rightarrow v_f^2 - v_i^2 = 2g\Delta y$

Look familiar ?!!

Ramp example



Assume constant speed

Pushing: work done is $W = \int \bar{F} \cdot d\bar{x} = \int (F_y \hat{y} + F_x \hat{x}) \cdot dx\,\hat{x}$

But what are the components of the force?

$\hat{y}: N - Mg\cos\theta = 0 \Rightarrow N = Mg\cos\theta$ } Newton's 2nd law

$\hat{x}: F_{ext} - Mg\sin\theta = 0 \Rightarrow F_{ext} = Mg\sin\theta$ ← F_x

So $W = \int F_y\, dx\, \underbrace{\hat{y}\cdot\hat{x}}_{=0} + \int F_x\, dx\, \underbrace{\hat{x}\cdot\hat{x}}_{=1}$

$= \int F_x\, dx$

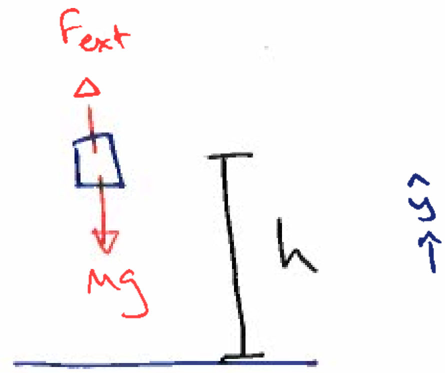
$= \int_0^L Mg\sin\theta\, dx$

$= Mg\sin\theta \int_0^L dx$

$= Mg\sin\theta\, x\Big|_0^L = MgL\sin\theta$

But $\sin\theta = \frac{h}{L} \Rightarrow W = MgL\cdot\frac{h}{L} = \underline{Mgh}$

Lifting : work done is entirely expressed in terms of vertical external force



$$W = \int \bar{F}_{ext} \cdot d\bar{y}$$

$$= \int F_{ext}\, dy \underbrace{\hat{y}\cdot\hat{y}}_{=1}$$

$\leftarrow$ $\bar{F}_{ext} = F_{ext}\,\hat{y}$

$d\bar{y} = dy\,\hat{y}$

To find the force, we use Newton's second law $(a=0)$

$$F_{ext} - mg = 0 \Rightarrow F_{ext} = mg$$

$$\Rightarrow W = \int F_{ext}\, dy$$

$$= \int_0^h mg\, dy$$

$$= mg\int_0^h dy = mg\,y\Big|_0^h = \underline{mgh}$$

The same!

Note the change in potential energy is

$$\Delta U = mg\cdot h - mg\cdot 0 = mgh$$

Power (slide 11)

kwh = unit of energy
= 1000 Watts . hours
= 1000 × 3600 = 3.6×10^6

$$P = \frac{dE}{dt}$$ – units are J/s ≡ Watt (kg m²/s²)

Transfer through work

$$P = \frac{dW}{dt} = \frac{d(\bar{F}\cdot\bar{r})}{dt} = \bar{F}\cdot\frac{d\bar{r}}{dt} = \bar{F}\cdot\bar{v}$$

if $\bar{F}$ constant $\frac{d\bar{F}}{dt} = 0$