Mechatronics/AP Computer Science Principles - Summer 2024

As you should know, class involves mechanics, electronics, and computer science. You will design, build, and interact with mechanical systems containing gears, levers, and motors. These systems will be connected to sensors and components in electronic circuits and be controlled using computer programs you create! We see this in drones, robotic arms, and self-driving cars. Those systems can be incredibly complicated and involve teams of engineers working for months and years to build and improve their designs.

This class will primarily be students who took Mechatronics 1 this past year; however, there will be a few who did not. Make sure you complete this as best you can. For my returning students, use this should be a refresher. We have plenty to do this year, so I'd like to get off on a good start

I've broken this packet into four sections:

Do not purge everything you learned in physics and math yet because we will be using plenty of it. Read through each section, attempt the practice problems, do some Googling, write a couple lines of code, and keep the concepts you learned this year fresh in your mind. Engineers need to pull all kinds of ideas together. You will do the same.

I hope to see you all in August. Until then, have a great summer!

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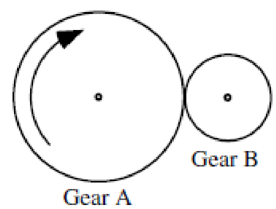
The Mechanics part of the class

If you are coming from an AP Physics class, you have some knowledge of torque and rotation. This is certainly the trickiest part of the curriculum for many. We will not be diving into the math of rotational inertia, but knowledge of angular velocity and torque are incredibly helpful when discussing motors and gears.

Gear ratios are simple to understand: if one gear is connect to another, the direction of spin will be opposite of each other and their speeds are dependent on the number of teeth on each gear (which is based on how big the gear is.) Ex: if a gear with 12 teeth is connected to a larger gear with 36 teeth, the smaller gear will turn three times faster than the bigger gear. This is a handy thing to know for people who design car transmissions.

With every aspect of engineering, there is a tradeoff: often it is speed for strength or distance. Work through these problems to apply the concepts of torque.

Gears -- They're what makes the world go round… that and conservation of angular momentum.



1. Gear A rotates clockwise driving a second smaller gear B without slipping. (The gear teeth are not shown.) The radius for gear A is twice as large as the radius for gear B.

    a. Is the magnitude of the angular velocity of gear A greater than, less than, or equal to the magnitude of the angular velocity of gear B? Explain.

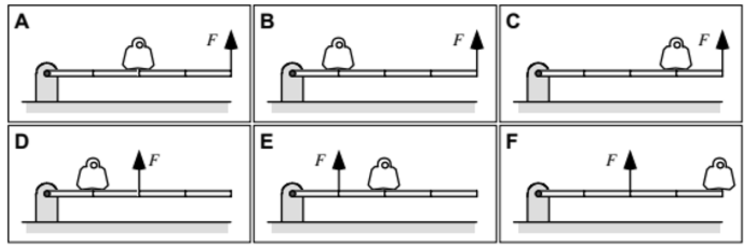
    b. Is the magnitude of the linear velocity of a point on the edge of gear A *greater than, less than,* or *equal to* the magnitude of the linear velocity of a point on the edge of gear B? Explain.

    c. Is the total number of gear teeth for gear A greater than, less than, or the same as the total number of gear teeth for gear B? Explain.

    d. Is the direction of the angular velocity of gear B the same as gear A, opposite to gear A, or is it impossible to compare the direction of the angular velocities of the two gears?

Levels -- Trading force for distance

Wheelbarrows are handy because they let you lift heavy loads much easier than it would be without the aid of the wheelbarrow. The wheel is there to help you move it from place to place, but the mechanical advantage behind the actual lifting is based on where the load is place and where you lift it.



In the case of the wheelbarrow, you lift up the handles further than the actual load raises. The image to the right is essentially a wheel-less wheelbarrow (just a barrow?) Use the image to answer the following questions.

1. Rank the force needed to hold the mass in place.

2. A larger force is now applied that can actually lift the mass. If the point on the rod at F is lifted the same height in each case, rank the cases based on how far *the mass* moves.

3. ***Challenge:*** Let's put some numbers to this -- the length of the rod is 4 m and the mass is 5 kg. If you lifted the rod 1 m, how high is the mass lifted in each case? Can you determine the vertical distance and the actual displacement? *(Yes, this involves a decent amount of trig and it's ok if you decide to skip this one.)*

What you need to take from this exercise is that the application determines where you place objects and how everything is connect. Which of the above would be best at lifting the object with the least force, and which would be best at lifting the object the highest?

The Computer Science part of the class

A key part in determining how effective a design is involves collecting and analyzing data.

Microsoft Excel and its Google counterpart Sheets can serve many purposes. The one of the primary purposes is for accounting and financial bookkeeping. We will be using Excel in this class as an introduction to programming and as a way to analyze data.

The link below takes you through many of the features of Excel, you can easily find the equivalent features in Sheets, you just may have to do a bit more hunting.

https://edu.gcfglobal.org/en/topics/excel/

If you have Excel, great! If not, you can use Google Sheets as a workaround or go to a library (when/if they open) that will likely have a version (maybe an older version, but probably still useable) that you can use for free.

The following lessons will get you well acquainted with Excel's capabilities and does a great job introducing you to programming.

- Lessons 1-12 - the basics of Excel, many of you already know the basics or can figure it out, but you'll probably find a trick or a shortcut that will come in handy at some point
- Lessons 13-16 – formulas and functions, this is the heart of it. Don't expect to know all the functions or memorize all the arguments for each, but recognize what they are and how to use them
- Lessons 17-24 – working with data, this will help you sort through the data and find the trends and important things
- Lessons 25 - 36 – extras, very optional and not especially relevant to our class but good to know

The programming languages we will be using (to varying degrees) are Scratch, [Circuit] Python, and a version of C that is customized for Arduino. They all have their own quirks and, just like Spanish, English, French, and every other written/spoken language, there are rules that vary between languages; however, there are many similarities.

Mathematics and Computer Science were once hand in hand. The divide has grown, but the basic principles of variables and utilizing equations are at the heart of most programming languages. We won't necessarily be using trig functions and derivatives, but solid algebra skills will be handy.

The Electronics part of the class

There are plenty of parts, pieces, and devices we will use throughout the course. However, they all start with understanding the fundamental concepts of circuits. That means the simple circuits you saw in Physics class with resistors, batteries, and switches. Capacitors, diodes, LEDs, transistors, transformers, and other components will come in due time.

You may be rusty on some of the key principles or you never quite got them the first time. Regardless, we will be applying the concepts or series and parallel circuits over and over. I have included some problems to [re-]familiarize yourself with everything so we can hit the ground running and building when we meet next year.

You can find lots of resources here: http://fusia.weebly.com/resources It's the resources page of my website; I will also create a class page to post additional information and interesting things. This is NOT intended to be something to check regularly over the summer, just a place to find info.

Look through these terms and make sure you understand their meaning. Look up their definitions online, but make sure you are looking at their meaning *in terms of electronics*.

Voltage drop	Bias	Analog v digital
Polarity	Transistor	Grounding
Diode	Capacitance	Transducer
Anode	Voltage regulator	Sensors
Cathode	Logic	Actuator

Here are concept problems that you should recall from Physics. Make sure you understand the relationships between voltage, current, and resistance as well as the difference between parallel and series. You will be designing your own circuits so you need to know when and why either is used.

1. What is voltage?
    a. What is the unit?
    b. What are some examples of voltage sources?
    c. If there is no voltage then there is no ________.

2. What is current?
    a. What is the unit?
    b. What must be present for the current to flow?

3. What is resistance? It's unit?

4. What is electrical power? It's unit?

5. Why can a bird perch on high voltage wires?

6. What is AC and DC? What are examples of each type of current?

7. In a series circuit, what happens to the brightness of the bulbs as more are added to the circuit? What happens if one light goes out?

8. In a parallel circuit, what happens to the brightness of the bulbs as more as added to the circuit? What happens if one light goes out?

9. What is Kirchhoff's Voltage Law (the Loop Law)?

10. What is Kirchhoff's Current Law (the Junction Rule)?

CALCULATIONS

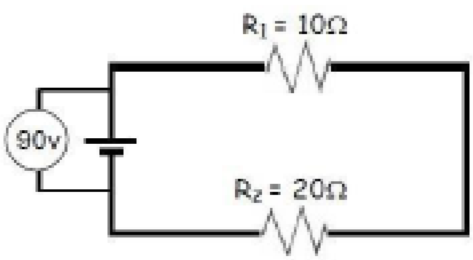
1. A flashlight has a resistance of 4.0 ohms.
   a. How much current does the lightbulb draw when it is run off a 9V battery?
   b. How much power does the lightbulb use?

2. Which has more resistance when plugged into a 120 V line, a 60-watt light bulb or a 90-watt can opener?

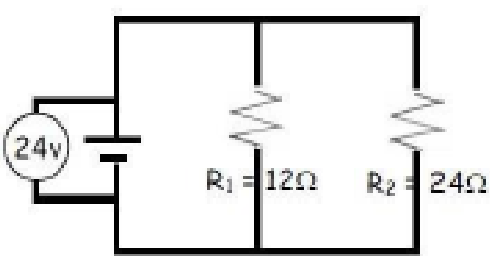
3. If a circuit is connected in series, what is the total resistance if it has 4 Ω and 5 Ω resistors?

4. If a circuit is connected in parallel, what is the total resistance if it has 4 Ω and 5 Ω resistors?

Complete the tables for the following circuits.



	V	I	R
1			
2			
Total			



	V	I	R
1			
2			
Total			

Other Stuff

I'm including two things in this section: math and resources.

Math

When I mention math in this section, I'm not referring to solving complex algebra problems or using logarithms. I'm referring to metric notation. You have seen this before, but it may have been a while and you likely never applied it.

The numbers you plugged into Ohm's Law (V = IR) in Physics looked like 2 A and 10 Ω; but in electronics, we deal with values like 47,000 Ω and 0.000 003 A. To simplify, we put them in engineering or metric notation, which is similar to scientific notation. Instead of 0.000 002 A we would turn it into scientific notation, but with the exponent being a multiple of 3, then replace the 10^x term with the appropriate prefix. So…

$$0.000\ 002\ A = 2.0 \times 10^{-6} = 2.0\ \mu A \quad (or\ 2.0\ microamps)$$

I included some practice on the next page. Once you do this a few times, you will become very familiar with it. The prefixes we will use are in this table

Giga-	Mega-	kilo-	(base)	milli-	micro-	nano-	pico-
G	M	k	--	m	µ	n	P
10^9	10^6	10^3	$10^0=1$	10^{-3}	10^{-6}	10^{-9}	10^{-12}

Examples:

Small numbers	Large numbers
.000000512 A (= .00000512 x10^0 A)	410, 000, 000 Ω (= 410, 000, 000 x10^0 Ω)
= .00000512 x 10^{-1} A	= 41, 000, 000 x 10^1 Ω
= .0000512 x 10^{-2} A	= 4, 100, 000 x 10^2 Ω
= .000512 x 10^{-3} A = .000512 mA	= 410, 000 x 10^3 Ω = 410, 000 kΩ
= .00512 x 10^{-4} A	= 41, 000 x 10^4 Ω
= .0512 x 10^{-5} A	= 4, 100 x 10^5 Ω
= .512 x 10^{-6} A = .512 µA	= 410 x 10^6 Ω = 410 MΩ
= 5.12 x 10^{-7} A	= 41 x 10^7 Ω
= 51.2 x 10^{-8} A	= 4.1 x 10^8 Ω
= 512 x 10^{-9} A = 512 nA	= .41 x 10^9 Ω = .41 GΩ

Recall some of your math lessons involving exponents to solve equations like Ohm's Law that uses large and small numbers. A 9 V battery is connected across a 47 kΩ resistor. How much current does the resistor draw from the battery? (Notice the exponent goes negative when it is moved from the denominator to the numerator)

$$V = I\,R$$

$$9\,V = I \times 47\ k\Omega$$

$$\frac{9\,V}{47 \times 10^3} = I$$

$$0.19 \times 10^{-3} = I$$

$$0.19\ mA = I \quad or\ I = 190\ \mu A$$

Put these numbers in metric notation

1. 26000 V ______________________________
2. 2300000 Ω ______________________________
3. 0.023 A ______________________________
4. 412000 Ω ______________________________
5. 0.0008 A ______________________________
6. 12 V ______________________________

Solve the problems below. Your answer should be in proper metric notation.

7. 36 kΩ + 12 k Ω = ______________________________
8. 120 Ω x 7 mA = ______________________________
9. 1.2 kV + 50 V = ______________________________
10. 27 V – 12 A = ______________________________
11. 18 V ÷ 1.5 MΩ = ______________________________
12. 3.3 kΩ – 180 Ω = ______________________________

<u>**Math operation rules:**</u>

Adding and Subtracting: exponentials, prefixes, and units must match. The answer may need a new prefix, unit will stay the same

Multiplying and Dividing: Exponentials, prefixes, and units do not need to match (and likely won't match). The answer <u>will</u> have a new unit and likely prefix.

Resources

If you are looking for resources to play around with over the summer, below is a list of things we will use to varying degrees throughout the year. Some are for circuits, some are for programming. Some are free, some are not. Some are available online, some require you download/install them on your computer. All of them are optional (for now.)

What?	Where?	Why?
Arduino	http://www.Arduino.cc	Download the IDE (the place where you will write your code) that will eventually send your program to the Arduino. You can also find an extensive reference library here.
Codecademy	https://www.codecademy.com/learn	Learn a number of different programming languages. The Python lessons are extensive, but C++ is great too. The free version is good, but a paid version with support is available if you like.
Google	You'll need to Google it	There's some terrible stuff on the internet, but you'll also find HUGE communities of very helpful people that have created tutorials and guide to help you through whatever problem your having.
Every Circuit	https://everycircuit.com/	Great way to build semi-professional-looking, semi-complex circuits online (or on your phone). The free version won't get you too far, but the lifetime unlimited version is only a one-time $15.
LTSpice	https://www.analog.com/en/design-center/design-tools-and-calculators/ltspice-simulator.html	Use only if you know what you're doing or you just want to see what the pros are using (mostly)
Mu	https://codewith.mu/	A downloadable shell for python. You can find similar ones for most languages if you search for them.
Scratch	https://scratch.mit.edu/	Free online account to get you started with block programming. Usually a beginner programming language, but advanced programmers can still make cool animations and games!
TinkerCAD	https://www.tinkercad.com/	More than just basic software to design 3D models. You can also design a circuit, connect it to an "Arduino" AND program all in the same place.
Youtube	http://youtube.com	See also: Google