Unit 21 – Session 1

Last semester, we explored a number of different force types:

1) Gravitational force, $\vec{F}^{grav} = m\vec{g}$.
2) Normal force, $\vec{F}^{norm}$
3) Tension force, $\vec{F}^{tens}$
4) Friction force, $\vec{F}^{fric}$

It turns out that the last three forces are all just due to the electric force at the molecular level – charges repelling each other (normal) or attracting each other (tension, friction)

It also turns out that two objects with the property of mass interact with each other in an extremely similar way as two objects with the property of charge. In fact, there is a gravitational force law (Newton's universal law of gravitation) for two objects with mass that looks very similar to Coulomb's law for two objects with excess charge.

Electrical (Coulomb's law)		**Gravitational (Newton's universal law of gravitation)**
$\vec{F}^{elec}_{\substack{\text{on }A\\ \text{by }B}} = \frac{kq_A q_B}{r^2}\hat{r}$		$\vec{F}^{grav}_{\substack{\text{on }A\\ \text{by }B}} = \frac{-Gm_A m_B}{r^2}\hat{r}$
$k = 8.99\times10^{9}\,\frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}}$		$G = 6.67\times10^{-11}\,\frac{\mathrm{N\cdot m^2}}{\mathrm{kg^2}}$

The expression we've previously been using, $\vec{F}^{grav} = m\vec{g}$, is a special case for when the Earth is one of the two interacting objects with mass, and the other object is near the surface of the Earth.

Activity 21.2.1.

Hopefully, you came up with these ideas.

a. Similarities:

1) (k) and (G) — both force laws depend on a universal constant ("universal" means the constant has the same value everywhere in the universe, not just here on Earth).
2) ($q_A q_B$) and ($m_A m_B$) — both force laws depend on the product of a property of the two objects.
3) $1/r^2$ — both force laws are inverse square laws (the magnitude of each force decreases a lot as the objects are separated more and more).
4) $\hat{r}$ — both forces are vectors, with the forces acting parallel to a line connecting the centers of the two objects (the force on one object is directly toward or directly away from the other object).

b. Differences:

1) (k) and (G) — In addition to units (C^2 vs. kg^2), the values are significantly different, with k being very large and G being very small.
2) ($q_A q_B$) and ($m_A m_B$) — $\vec{F}^{elec}$ depends on the property of charge, while $\vec{F}^{grav}$ depends on the property of mass. Also, there are two types of charge, + and –, but only one type of mass, +.
3)
4) $\hat{r}$ — $\vec{F}^{elec}$ is repulsive for like charges, and attractive for unlike charges (this is taken care of by the + and – signs of the charges). $\vec{F}^{grav}$ is always attractive (this is taken care of by the – sign in the expression for the gravitational law, making $\vec{F}^{grav}$ always in the opposite direction of $\hat{r}$).

Activity 21.3.1

- Part **c**. – Just to make sure your calculations in parts **a.** and **b.** are working ok, you should get: $factor = \frac{\left|\vec{F}^{elec}\right|}{\left|\vec{F}^{grav}\right|} = 2.3\times10^{39}$.

- Part **d**. – There is no one answer to this question – it is whatever your experience is. For example, when I do an endo when mountain biking, I'm very aware of the gravitational force. On the other hand, just combing my hair makes it out of control due to the electrical force from the excess charge.

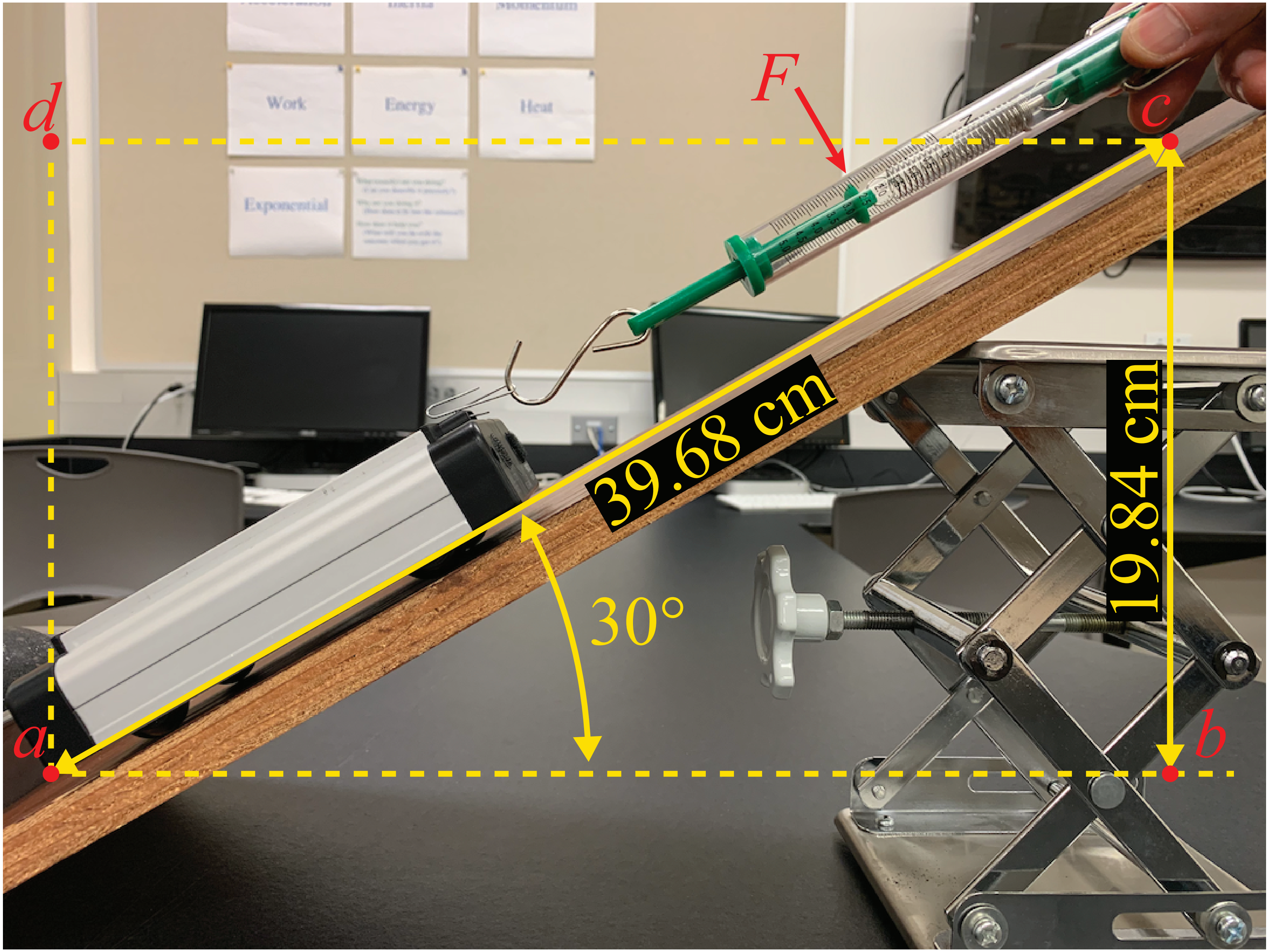
Activity 21.4.1

- Revisit your answer to Activity 20.5.2 on page 562. Remember that the electrical Gauss' law is $\left|\vec{E}\right|\left|\vec{A}\right|\cos\theta = 4\pi k q^{enclosed}$, where the electric field vector was defined as $\vec{E} \equiv \vec{F}^{elec}/q$.
- Look back at Activity 21.2.1 to remind yourself of the similarities and differences between Coulomb's law and Newton's universal law of gravitation, and to use them to help you make the connection between electrical Gauss' law and gravitational Gauss' law. (Don't forget that Newton's universal law of gravitation has a minus sign – it's important here as well.)

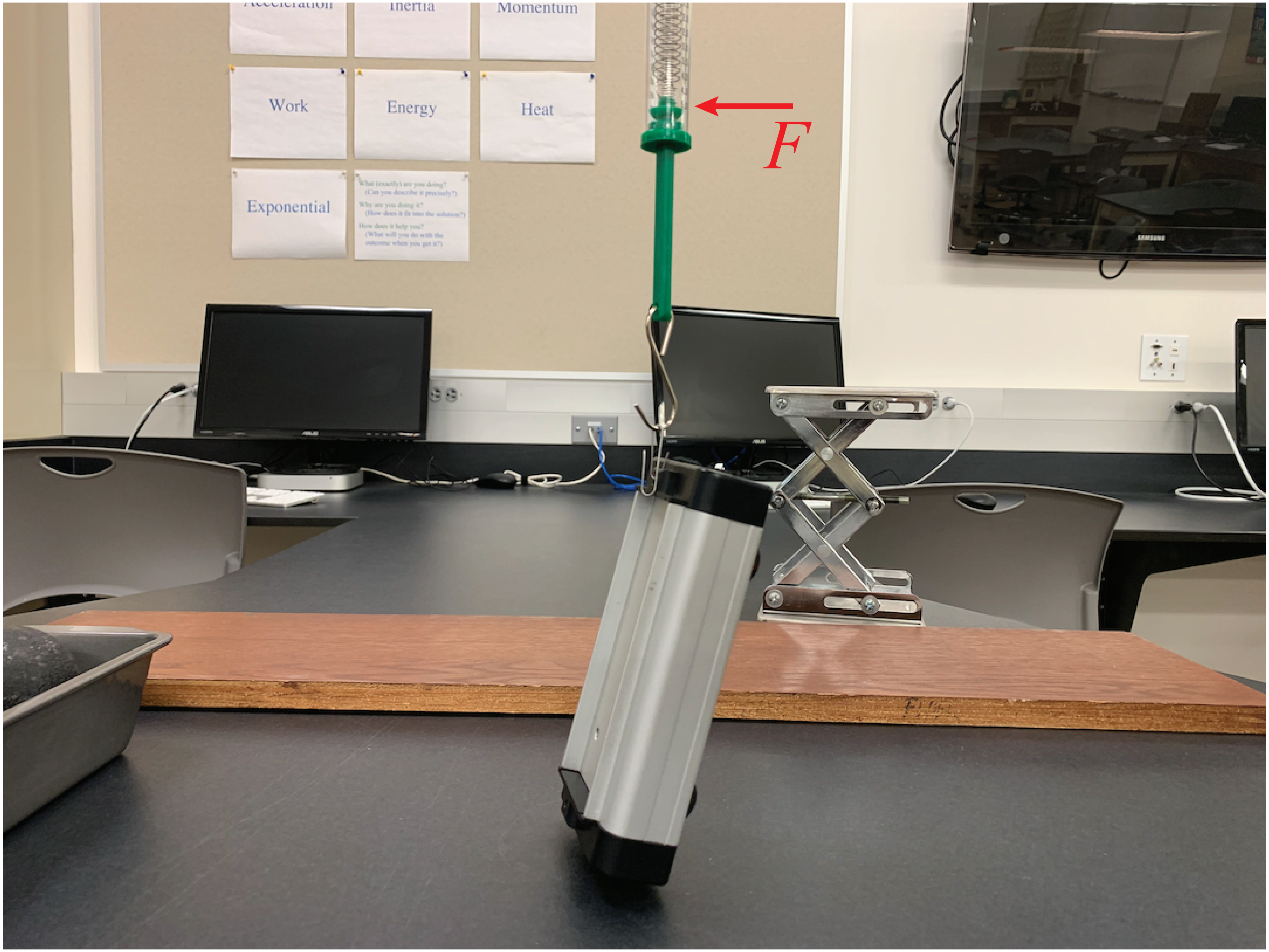
Activity 21.5.1

- Part **a.** – The image on the next page of these notes shows the reading on the 5.0 N spring scale as I pulled the cart (at constant speed) along the inclined plane. I pulled the bottom left of the cart from point *a* to point *c*. Be careful here; when calculating the work, the angle, θ, is **not** 30°. Which direction does $\vec{F}^{spring\,scale}$ point? Which direction does $\Delta\vec{s}$ point? (You did something similar last semester when you bid on the 3 jobs lifting boxes in Activities 10.2.1 and 10.4.2.)
- Part **b.** – The image following the one on the next page shows the reading on the 5.0 N spring scale as I lifted the cart from point *a* to point *d*, then moved it sideways from point *d* to point *c*, all at constant speed. Again, for each of the two separate paths, think about the angle, θ, between the vectors $\vec{F}^{spring\,scale}$ and $\Delta\vec{s}$.

Activity 21.5.1 a.



Activity 21.5.1 b.



Activity 21.6.1

For all three cases, both the electric field, $\vec{E}$, and the angle, θ, are constant for the whole path, so we can use:

$$\begin{aligned} W^{elec} &= \left|\vec{F}^{elec}\right|\left|\Delta\vec{s}\right|\cos\theta \\ &= q_t\left|\vec{E}\right|\left|\Delta\vec{s}\right|\cos\theta \end{aligned}$$

(no scary integral needed)

Unless otherwise stated, it is usually assumed that a test charge, q_t, is a positive type of charge.

$$\begin{aligned} \cos 0^\circ &= 1 \\ \cos 45^\circ &= 0.71 \\ \cos 90^\circ &= 0 \\ \cos 135^\circ &= -0.71 \\ \cos 180^\circ &= -1 \end{aligned}$$