ED01 Get Real! - Appropriate Values for Teaching Physics

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A simple mechanics problem

A pastiche of several MC problems I have reviewed:

A student uses a force probe to exert an average force of 24 N on a 6 kg lab cart for 5 seconds. The cart travels on a straight track. The cart wheels have negligible drag. Find the change in the cart's momentum.

Analysis

$$\Delta p = F\Delta t = 120 \text{ N-s}$$

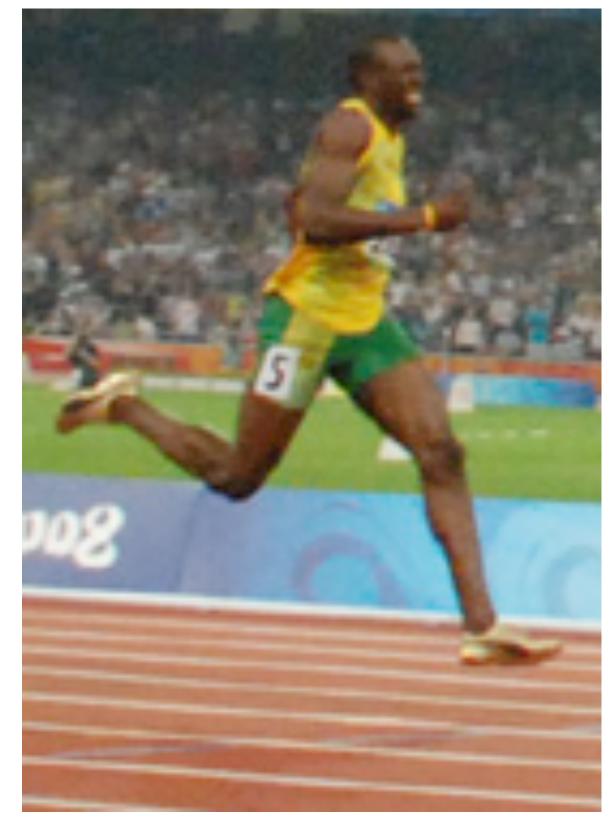
Look deeper: acceleration = 4 m/s^2. Starting from rest, after 5 s *v* = 20 m/s and *d* = 50 m.

Basic mechanics, simple numbers, no calculator needed.

Wait a minute!

13 pound lab cart! That would be
12.5 pound on 0.5 pound PASCO™ lab cart?

Final speed of cart and student :
72 km/h = 44 mph = 1.6 Usain Bolt top speed



Distance traveled in classroom: 60 yards
Classroom size > 0.5 football field

Track = 23 PASCO™ 2.2 meter tracks end to end

Student hopes to stop safely

50 college track coaches beating down the door to reach him first

Should we worry? Why?

Simple concept, easy numbers, BUT physics is more than just crunching numbers in equations.

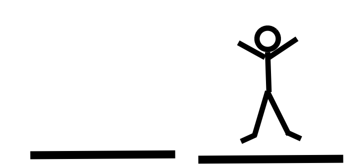
Physics builds, tests & uses *plausible* models of real world.

Can we use easy numbers?

For novices, numbers should be as simple as possible, but not simpler (paraphrasing Einstein's Razor)

Mastery exams should reward <u>robust</u> knowledge.

Student should reject 20 m vertical leap but accept 20 cm. If 20 m is "correct" answer, we are cheating good students.



MOST textbooks seem to use realistic values in mechanics.

Proposed problem preparation principles.

Physically reasonable values and units should provide experience with real world magnitudes.

Problem values situated in a class or lab context should be consistent with achievable results in that context.

If values are from some other context, that should be clearly stated.

If unrealistic values are used, clear notice should be given or students should be cued to challenge the realism of the given values. (e.g., R. Munroe's <u>What If</u> book)

Problems in electrostatics

Examining about 20 texts, many authors seem to have little feel for realistic values of charges, fields, size & mass of charged objects on classroom scale.

In past, few tools at hand to measure charge

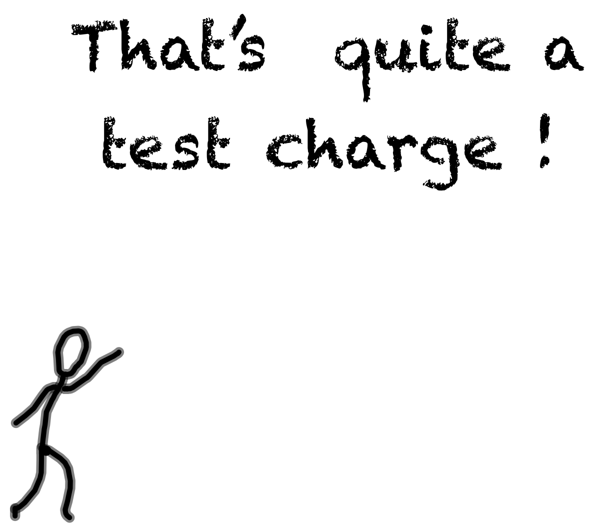
We now have affordable charge sensors such as Vernier™ & PASCO™ computer interfaced sensors.

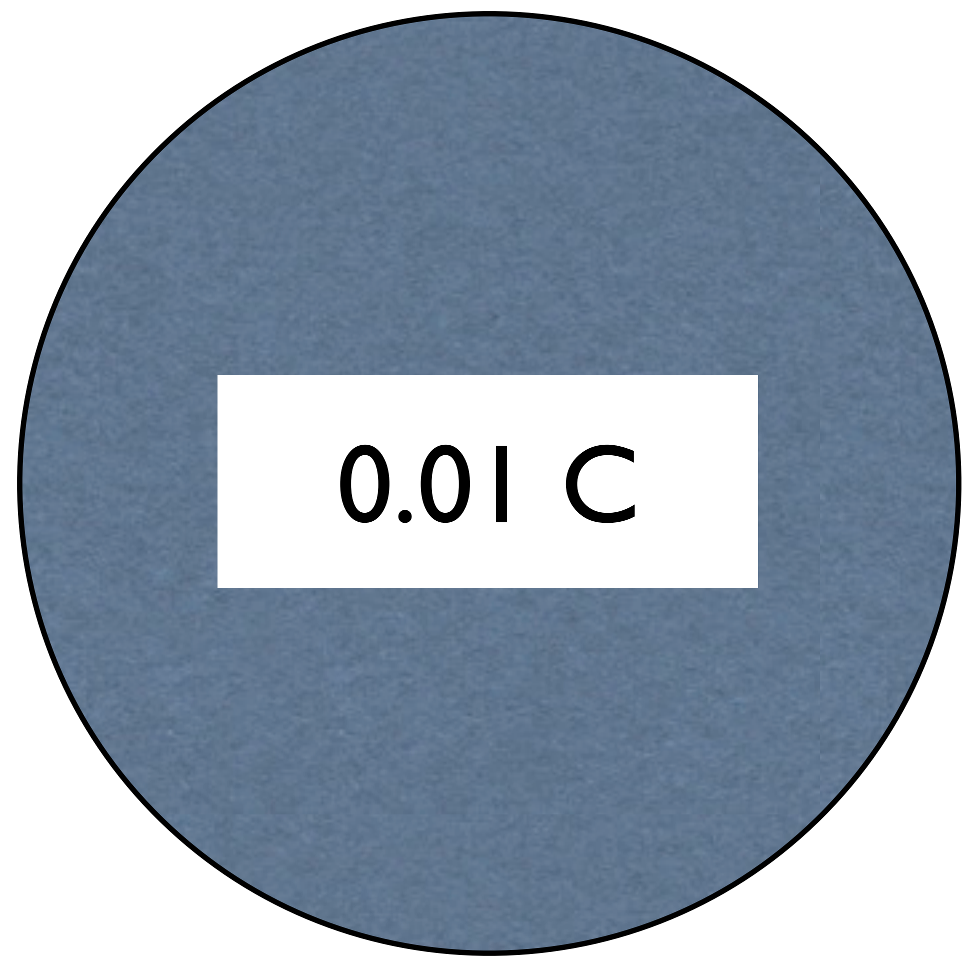
Texts give electric breakdown strength of air 3 x 10^6 N/C, so the breakdown surface charge density is about 27 μC/m^2

Minimum radius of sphere for given charge $R_{\min} = 55\left({}^{m}\!/\!_{C^{\frac{1}{2}}} \right)\sqrt{Q}$

Maximum charge for given radius $Q_{\max} = 0.33\times 10^{-3}\left({}^{C}\!/\!_{m^2} \right)R^2$

Is 1/100 of a Coulomb a small test charge?



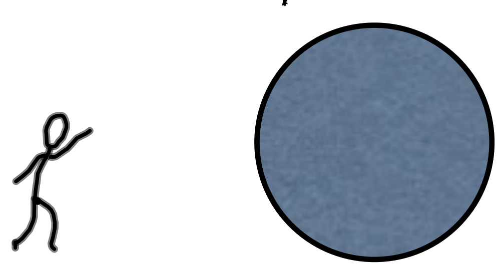


Examples of Realistic Values

Charge & R_{min}

Charge	R_{min}
1 C	55 m
1 mC	1.7 m
1 μC	5.5 cm
1 nC	1.7 mm

That's still quite a test charge !



1 mC

Measured charges in lab

Styrofoam cup	60 - 90 nC
soda can charged on VDG	70 nC
plastic straw	20 nC
4 cm dia ping pong ball rubbed with acrylic	20 nC
4 cm Scotch™ tape	8 nC
Al foil cylinder 5 mm x 1cm	5 nC

Ref:

R. A. Morse, "Electrostatics with Computer-Interfaced Charge Sensors," TPT, 44(3) 2006

A charge too large

Microcoulomb sounds small but is large at lab scale (dia ~ 11 cm)
Many text problems have object sizes too small for given charge

Find net force exerted on 1μC test charge halfway between 5 μC and 2 μC charged spheres with centers 10 cm apart.

R_{min} of spheres must be 5.5 cm, 12.3 cm, 7.8 cm respectively.

Place 5 μC and 2 μC objects in contact, centers are 20 cm apart, twice the specified separation, so no room for 1 μC , 11 cm diameter object in between.

Compare	15 cm diameter Van De Graaff 2 μC
maximum	30 cm diameter 450 kV VDG 7 μC
charges	1 cm diameter pith ball only 8.3 nC

A field too strong

Find external electric field strength to exert 15 N force on a small pellet with a 3nC charge

Result: $E = 5\times10^9$ N/C

~1700 times $E_{breakdown}$

15 N force is huge!

3 nC styrofoam pellet has R_{min} about 3 mm.

Styrofoam density100 kg/m^3 gives mass of 0.11 μg,

If released, acceleration is 140×10^6 m/s^2

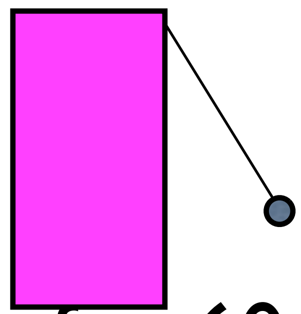
speed after 1 cm is 1.7 km/s

comparable to high velocity rifle bullet

Don’t let go of that in the lab!

Impossible materials

Common problem situation: a 10 gram sphere with a 60 μC charge hangs from a string. Its center is 30 cm from the other end of the string which is attached to a charged vertical wall.



Stop right there.

R_{min} for 60 μC is 42 cm so whole string is inside the sphere!

From mass and R_{min}, volume is 0.32 m^3 & density 0.031 kg/m^3

At STP, densities of air and hydrogen gas are 1.3 & 0.090 kg/m^3.

What material can we use to make a 2 foot diameter ball with average density a third that of hydrogen gas?
(aerogels are still too dense)

Suggestions

Authors - Please take care - choose realistic values.

Teachers - with many present texts you may want to revise electrostatics problems so they make physical sense. Consider enlisting students to check problems and devise realistic replacement values. Finding mistakes in authoritative texts is BOUND to have student appeal.

(Students - if writing authors, please do it *most* politely.)

We all make mistakes. Writing good books and good problems is hard, but we owe it to our students to be careful.