Physics Challenge for Teachers and Students

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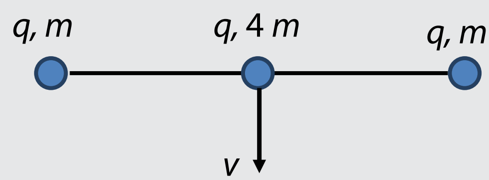
Solution to March 2017 *Challenge*

Know strings attached!

Three small metal charged balls have equal charges q and masses *m*, 4*m* and *m*. The balls are connected by light non-conducting strings of length *d* each and placed on a horizontal non-conducting frictionless table. Initially, the balls are at rest and form a straight line as shown. Then, a quick horizontal push gives the central ball a speed *v* directed perpendicular to the strings connecting the balls. Find the minimum subsequent distance between the balls of mass *m*.



Solution:

Initially, the kinetic energy of the system is defined solely by the mass in the middle:

$$KE = \frac{1}{2}(4m)v^2 = 2mv^2.$$

Similarly, for the linear momentum: $P = 4mv$.

After that, the motion of the three charges will follow a cyclic pattern where the center of mass will move at constant velocity in the direction of v and the three masses will oscillate in a symmetric way due to the electric repulsion between them and the strings that constrain the masses.

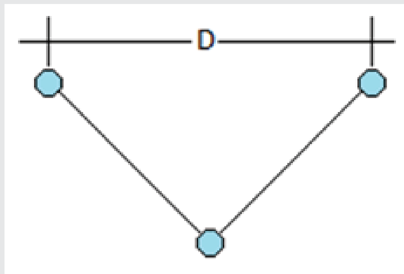
Conservation of momentum gives the center of mass velocity

$$v_{\mathrm{CM}} = \frac{4mv}{6m} = \frac{2}{3}v.$$

The kinetic energy associated with this motion of the center of mass is

$$KE_{\mathrm{CM}} = \frac{1}{2}(6m)\left(\frac{2v}{3}\right)^2 = \frac{4m}{3}v^2.$$

The minimum distance between the side charges occurs when the velocities with respect to the center of mass equal zero.



Then the difference in kinetic energy is traded for difference in electric potential energy.

$$2mv^2 - \frac{4m}{3}v^2 = \frac{q^2}{4\pi\varepsilon_0}\left(\frac{1}{D} - \frac{1}{2d}\right).$$

Solving for *D*, we get:

$$D = \frac{2d}{1 + \dfrac{16m\pi\varepsilon_0 dv^2}{3q^2}}.$$

(Submitted by Ramiro Moro, University of Engineering and Technology, Lima, Peru)

We also recognize the following successful contributors:

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- Pablo Bueno Martínez, student (Escuela Politécnica Superior, University of Seville, Seville, Spain)
- Phil Cahill (The SI Organization, Inc., Rosemont, PA)
- Daniel Cartin (Naval Academy Preparatory School, Middletown, RI)
- Norman Derby (Southwestern Oregon Community College, Brookings, Oregon)
- Elliot Fang, student (Farragut High School, Knoxville, TN)
- Bernard Feldman (University of Missouri-St. Louis, St. Louis, MO)
- Art Hovey (Galvanized Jazz Band, Milford, CT)
- José Ignacio Íñiguez de la Torre (Universidad de Salamanca, Salamanca, Spain)

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Guidelines for contributors:

- We ask that all solutions, preferably in Word format, be submitted to the dedicated email address *challenges@aapt.org*. Each message will receive an automatic acknowledgment.
- The subject line of each message should be the same as the name of the solution file.
- The deadline for submitting the solutions is the last day of the corresponding month.
- Each month, a representative selection of the successful solvers' names will be published in print and on the web.
- If your name is—for instance—Rick Perry, please name the file "**Perry17April**" (do not include your first initial) when submitting the April 2017 solution.
- If you have a message for the Column Editor, you may contact him at *korsunbo@post.harvard.edu*; however, please do not send your solutions to this address.

Many thanks to all contributors; we hope to hear from many more of you in the future.

We also hope to see more submissions of the original problems – thank you in advance!

Boris Korsunsky, Column Editor