Conestoga High School

Physics 3310-xx Mr. Kim

Name: ______________________________ Period: _____ Date: ____/____/____

Stopping Distance vs. Speed Lab

Names of people in your group: ____

____

____

☐ Each group will be assigned a specific coefficient of kinetic friction from 0.10 to 0.80. Then students, as a group, must first fill in the **guess column** of the stopping distance in **meters** of the given speed at *meters per second* in the data table.

$\mu_{kinetic}$ = ___	Stopping Distance	
Speed (m/s)	Actual (m)	Guess (m)
5	XXXX	_____
10	XXXX	_____
15	XXXX	_____
20	XXXX	_____
25	XXXX	_____
30	XXXX	_____
35	XXXX	_____
40	XXXX	_____
45	XXXX	_____
50	XXXX	_____

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☐ (*Optional*) Now fill in the **guess column** of the stopping distance in **feet** of the given speed at *miles per hour* in the data table.

$\mu_{kinetic}$ = ___	Stopping Distance	
Speed (mi/hr)	Actual (ft)	Guess (ft)
11.2	XXXX	______
22.4	XXXX	______
33.5	XXXX	______
44.7	XXXX	______
55.9	XXXX	______
67.1	XXXX	______
78.3	XXXX	______
89.4	XXXX	______
100.6	XXXX	______
111.8	XXXX	______

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As we have learned in our previous lessons whenever a moving object comes to a rest there has been a change in kinetic energy to a different form of energy such as potential energy, or as heat energy (created by work done by a frictional force on the rotors of the brakes which transfers to the tires). Although the physics of stopping a traveling automobile in a real world situation is much more involved than the kinetic friction between the tires and the road surface this exercise will give us a very good estimation of understanding of stopping distances of an automobile.

Assuming proper operation of the brakes on a vehicle are constant, the minimum stopping distance for a moving vehicle is determined by the effective coefficient of friction between the tires and the road surface, and the driver's reaction time in a panic-braking situation. The frictional force between the road surface and the tires must do enough work on the car to reduce its kinetic energy to zero. **If the wheels of the car continue to turn while braking, then static friction is in operation, BUT if the wheels are locked and they slide over the road surface (hydroplaning), the braking force is a kinetic friction force only.**

We will assume that the wheels are ***locked****, thus only the kinetic friction between the tires and the road surface is employed in this situation.*

$$W^{NC} = \Delta KE + \Delta U$$

But,

$$W^{NC} = W_{fr} = \vec{F}_{fr} \bullet \vec{d} = F_{fr} d \cos\theta_{F_{fr},d}$$

Since

$$\theta_{F_{fr},d} = 180^o, \ \cos\theta_{F_{fr},d} = \cos 180^o = -1$$

Therefore,

$$-F_{fr}d = KE_f - KE_i + 0 \text{ , since } \Delta U = 0.$$

But KE_f is also 0 because there is no final velocity, thus…

$$-F_{fr}d = -KE_i$$

You can cancel out the negative signs from both sides of the equation.

$$F_{fr}d = KE_i$$

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But…

$$F_{fr} = \mu_k F_N = \mu_k mg$$

And…

$$KE_i = \frac{1}{2} m v_i^2$$

Thus by substituting the $F_{fr} = \mu_k mg$ and $KE_i = \frac{1}{2} m v_i^2$ …

$$\mu_k mgd = \frac{1}{2} m v_i^2$$

Notice how the mass of the vehicle cancels out. This implies a stopping distance independent of vehicle mass, and in this case.

$$\mu_k gd = \frac{1}{2} v_i^2$$

Now if we solve for ***d***…

$$d = \frac{v_i^2}{2\mu_k g}$$

For calculating minimum stopping distance, a value of 0.8 would be a nominal acceptable value for the coefficient of kinetic friction between good tires and a good road surface. Almost, if not always, coefficients of kinetic friction are less than the static coefficient of friction, and are significantly less for wet, slick, sandy, dirty, very smooth, oily, or icy surfaces. For most of the newer, high performance tires with good treads, the coefficient of kinetic friction and of static friction on a dry road surface may approach 0.8 if the braking is not so prolonged.

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☐ Now let us *estimate* what kind of value the kinetic coefficient of friction would have on some given tire conditions and road surfaces. Please fill in the given data table below as a group by estimating what the value might be for the coefficient of kinetic friction.

Tire Condition	**Road Condition**	μ_k
Brand New Z-rated Tires	Hot and Dry	0.9
Z-rated Tires with 20% Tread wear	Dry	
Z-rated Tires with 50% Tread wear	Dry	
Z-rated Tires with 80% Tread wear	Dry	
Brand New Z-rated Tires	Wet	
Z-rated Tires with 20% Tread wear	Wet	
Z-rated Tires with 50% Tread wear	Wet	
Z-rated Tires with 80% Tread wear	Wet	
Brand New Z-rated Tires	Snow	
Z-rated Tires with 20% Tread wear	Snow	
Z-rated Tires with 50% Tread wear	Snow	
Z-rated Tires with 80% Tread wear	Snow	
Z-rated Tires with 90% Tread wear	Icy	

☐ Can you see how some coefficient of static friction overlaps depending on the tread wear and the road condition?

☐ Compare your results with other lab groups and discuss the differences and try to convince each other why your group selected the particular coefficient of kinetic friction for the given conditions.

☐ Now using the derived equation from above each group must calculate the stopping distance for each given speeds and the given coefficient of static friction and fill in the data table for the **actual stopping distance**. Also transfer your guessed values on the same data table below.

$$d = \frac{v_i^2}{2\mu_k g}$$

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$\mu_{kinetic}$ = ____	Stopping Distance	
Speed (m/s)	Actual (m)	Guess (m)
5	______	______
10	______	______
15	______	______
20	______	______
25	______	______
30	______	______
35	______	______
40	______	______
45	______	______
50	______	______

□ Now let's see how correct we were with our stopping distance guesses. First we will make a scatter plot of Guessed vs. Actual on MS Excel or on the graph paper provided by your instructor.

This means the Guessed column will be the dependent (vertical) axis and the Actual column will the independent (horizontal) axis.

For the Excel users you must remember to place the independent variable (Actual) in the first column and the dependent variable (Guessed) in the second column.

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Let's think for a moment!

1. If all of our guessed values is completely correct with the actual values what would the graph look like?

2. If all of our guessed values is completely correct with the actual values what would the ***slope*** value be?

☐ Now add a **linear** trend line for your scatter-plot and display the equation of your graph and the R^2 value on your chart.

What is your slope value? ______________________

Is it possible for you to get a negative slope value? Please explain…

What does it mean if you get a huge slope value or a very small slope value? Please explain…

Is it possible for you to get a ZERO slope value? Please explain…

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What is your R^2 value? ________________

What do you think the R^2 value represents?

Comparing your data for the given Speeds and the Actual Stopping Distances could you estimate what kind of graph these data points will produce? Please explain…

□ Now, lets make a scatter plot for the Actual Stopping Distance versus the Speed. Since the speed is the independent variable (horizontal axis) you should place it in the first column for the Excel users.

What kind of graph is this? Linear? Quadratic? Log?
If you chose quadratic, you must select the trend line of polynomial of order 2.

Using logic, how would you be able to convince someone that the y-intercept for your graph should be zero? Please explain…

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Using your graph, what is the stopping distance for 20 m/s? ______

Again, using your graph, what is the stopping distance for 40 m/s? ______

How much bigger (or how many times bigger) is the stopping distance for the 40 m/s when compared to the 20 m/s?

By looking at the derived equation, $d = \frac{v_i^2}{2\mu_k g}$ could you explain this?

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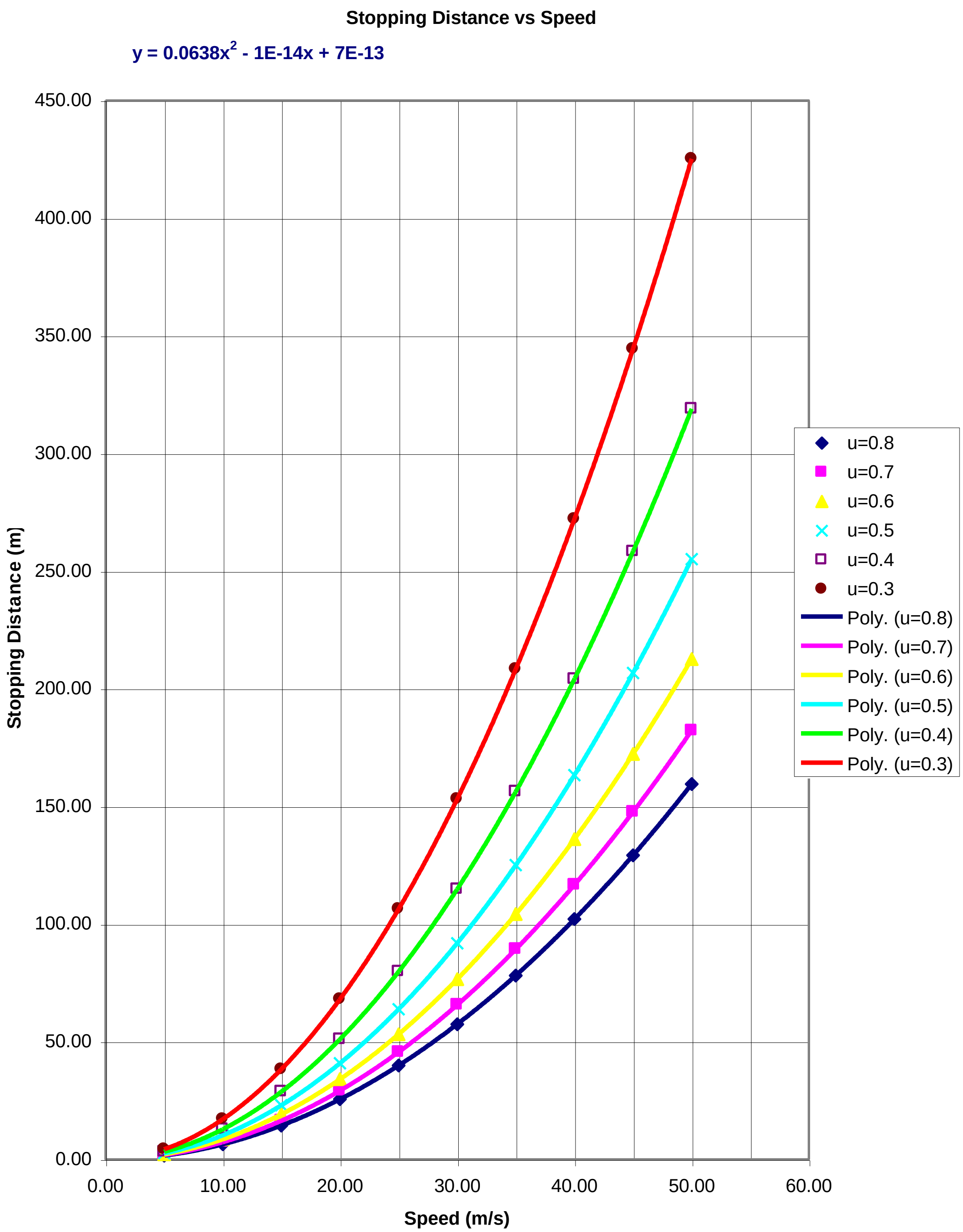

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Name: ____________________________ Period: _____ Date: ____/____/____

Looking at the value of your stopping distance from your graph at 30 m/s could you estimate what the stopping distance might be for 60 m/s? *You can get the stopping distance value by hovering your mouse over the data point at 30 m/s.*

Estimated stopping distance at 60 m/s: _____________meters.

☐ Please extrapolate (forecast forward) your graph 15 m/s on your trend line at the options menu. Simply right click on your trend line and select [Format Trendline…]. Then click [Options] tab. Find the [forecast] option and set the value to 15. While you are here you can also set the y-intercept value to zero by just checking the [set the y-intercept to zero] box.

By looking at your new graph could you estimate what the stopping distance value is at 60 m/s? ___________meters.

Is it about the same as your previously estimated value? ________

What is the stopping distance for 20 m/s? ______

What is the stopping distance for 60 m/s? ______

How much bigger (or how many times bigger) is the stopping distance for the 60 m/s when compared to the 20 m/s?

By looking at the derived equation, $d = \frac{v_i^{\ 2}}{2\mu_s g}$ could you explain this?

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So… What did we learn today by completing this exercise?

When you double your speed the stopping distance increases by ______ times the stopping distance of the original speed.

If you triple your speed then the stopping distance increases by ______ times the stopping distance of the original speed.

Therefore…

DRIVE SAFELY,
SLOW DOWN!!!
DON'T TAILGATE!!!
Especially with bad tires in a bad weather condition!!!
This knowledge may save your life or someone else's!!!

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Name: ______________________________ Period: _____ Date: ____/____/____

Static Coeficient of Friction = 0.8										
v (m/s) =	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00
v (km/h) =	18.00	36.00	54.00	72.00	90.00	108.00	126.00	144.00	162.00	180.00
v (mi/h) =	11.18	22.36	33.54	44.72	55.90	67.08	78.26	89.44	100.62	111.80
Static Coeficient of Friction =	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Stopping Distance (m) =	1.59	6.38	14.35	25.51	39.86	57.40	78.13	102.04	129.15	159.44
Stopping Distance (ft) =	5.23	20.92	47.07	83.67	130.74	188.27	256.25	334.69	423.60	522.96
Static Coeficient of Friction = 0.7										
v (m/s) =	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00
v (km/h) =	18.00	36.00	54.00	72.00	90.00	108.00	126.00	144.00	162.00	180.00
v (mi/h) =	11.18	22.36	33.54	44.72	55.90	67.08	78.26	89.44	100.62	111.80
Static Coeficient of Friction =	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Stopping Distance (m) =	1.82	7.29	16.40	29.15	45.55	65.60	89.29	116.62	147.59	182.22
Stopping Distance (ft) =	5.98	23.91	53.79	95.63	149.42	215.16	292.86	382.51	484.11	597.67
Static Coeficient of Friction = 0.6										
v (m/s) =	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00
v (km/h) =	18.00	36.00	54.00	72.00	90.00	108.00	126.00	144.00	162.00	180.00
v (mi/h) =	11.18	22.36	33.54	44.72	55.90	67.08	78.26	89.44	100.62	111.80
Static Coeficient of Friction =	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Stopping Distance (m) =	2.13	8.50	19.13	34.01	53.15	76.53	104.17	136.05	172.19	212.59
Stopping Distance (ft) =	6.97	27.89	62.76	111.56	174.32	251.02	341.67	446.26	564.80	697.28
Static Coeficient of Friction = 0.5										
v (m/s) =	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00
v (km/h) =	18.00	36.00	54.00	72.00	90.00	108.00	126.00	144.00	162.00	180.00
v (mi/h) =	11.18	22.36	33.54	44.72	55.90	67.08	78.26	89.44	100.62	111.80
Static Coeficient of Friction =	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Stopping Distance (m) =	2.55	10.20	22.96	40.82	63.78	91.84	125.00	163.27	206.63	255.10
Stopping Distance (ft) =	8.37	33.47	75.31	133.88	209.18	301.22	410.00	535.51	677.76	836.73
Static Coeficient of Friction = 0.4										
v (m/s) =	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00
v (km/h) =	18.00	36.00	54.00	72.00	90.00	108.00	126.00	144.00	162.00	180.00
v (mi/h) =	11.18	22.36	33.54	44.72	55.90	67.08	78.26	89.44	100.62	111.80
Static Coeficient of Friction =	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Stopping Distance (m) =	3.19	12.76	28.70	51.02	79.72	114.80	156.25	204.08	258.29	318.88
Stopping Distance (ft) =	10.46	41.84	94.13	167.35	261.48	376.53	512.50	669.39	847.19	1045.92

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Static Coeficient of Friction = 0.3										
v (m/s) =	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00
v (km/h) =	18.00	36.00	54.00	72.00	90.00	108.00	126.00	144.00	162.00	180.00
v (mi/h) =	11.18	22.36	33.54	44.72	55.90	67.08	78.26	89.44	100.62	111.80
Static Coeficient of Friction =	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Stopping Distance (m) =	4.25	17.01	38.27	68.03	106.29	153.06	208.33	272.11	344.39	425.17
Stopping Distance (ft) =	13.95	55.78	125.51	223.13	348.64	502.04	683.33	892.52	1129.59	1394.56

Static Coeficient of Friction = 0.2										
v (m/s) =	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00
v (km/h) =	18.00	36.00	54.00	72.00	90.00	108.00	126.00	144.00	162.00	180.00
v (mi/h) =	11.18	22.36	33.54	44.72	55.90	67.08	78.26	89.44	100.62	111.80
Static Coeficient of Friction =	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Stopping Distance (m) =	6.38	25.51	57.40	102.04	159.44	229.59	312.50	408.16	516.58	637.76
Stopping Distance (ft) =	20.92	83.67	188.27	334.69	522.96	753.06	1025.00	1338.78	1694.39	2091.84

Static Coeficient of Friction = 0.1										
v (m/s) =	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00
v (km/h) =	18.00	36.00	54.00	72.00	90.00	108.00	126.00	144.00	162.00	180.00
v (mi/h) =	11.18	22.36	33.54	44.72	55.90	67.08	78.26	89.44	100.62	111.80
Static Coeficient of Friction =	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Stopping Distance (m) =	12.76	51.02	114.80	204.08	318.88	459.18	625.00	816.33	1033.16	1275.51
Stopping Distance (ft) =	41.84	167.35	376.53	669.39	1045.92	1506.12	2050.00	2677.55	3388.78	4183.67