Experiment: **Free Fall Experiment (Fence)**

Purpose:

For researching free fall motion and measuring the value of acceleration due to gravity. The approach we use is to make a fence fall from a measured height and then record the time and velocity using a photogate. The value of acceleration due to gravity of each fixed grid width of a fence is averaged to calculate the closest result of acceleration due to gravity.

Theory:

From Kinematics:

$$V = V_0 + at \qquad (1)$$

$$S = V_0 t + \frac{1}{2} a t^2 \qquad (2)$$

$$V^2 = V_0{}^2 + 2aS \qquad (3)$$

When the instrument has already measured the first time t_0&t_1, we know the interval of the fence is 1 cm plus the width of the fence, so the width of each length plus the interval is 2 cm. Therefore, we can get the result of velocity $\overline{V}$ for each section.

(NOTE: In this situation, $\overline{V}$ isn't equal to initial velocity$\overline{Vi}$ or final velocity$\overline{Vf}$)

Each measured interval is 2 cm, so we assume the first length:

S_0=2, S_1=2+2=4

Then, we obtain the equation:

$$S_{n-1} = S_1 + (n \quad 1)d \qquad \textbf{d=2, n=1, 10} \qquad \textbf{(4)}$$

So

$$= V_i t_0 + \tfrac{1}{2} g t_0{}^2 \qquad S_0 \qquad \textbf{(5)}$$

$$S_1 = V_i t_1 + \tfrac{1}{2} g t_1{}^2 \qquad \textbf{(6)}$$

After calculating equation (5) & (6), we obtain

$$g = \frac{2(S_1 t_0 - S_0 t_1)}{t_0 t_1 (t_1 - t_0)} \qquad (7)$$

As a result, we obtain equation (7) to calculate the value of acceleration due to gravity for this experiment.

Instrument:

A11-111R-Y01 Photogate Electronic Timer- Free Fall equipment set(Including a free fall equipment stand x1, photogate x3, pad x1, electromagnet x1, fence x1)

As shown in Figure 1

Figure 1

Procedure:

First of all, we adjust the horizontal of stand's base.

The adjustments are:

1. First, adjust the 4 screws of the foundation to a certain height. According to the horizontal of the tabletop and the ground state, adjust the 4 screws on the base to a general horizontal.

2. Hang a plumb line down to the leveling rod, and then adjust the 4 screws on the base, so that the weight is suspended directly above the concavity on the rod. As shown in Figure 2

3. Roll the plumb line up and replace the leveling rod with a photogate. The adjustment of the horizontal is completely set.

Figure 2

I. After adjusting the horizontal, put the photogate in place and fix it. Choose the 'Fence' Mode (Mode 11) and then press the 'Reset' button on the timer to be ready to release the fence.

II. Press the 'Switch off' button to release the fence and let it fall smoothly past the photogate. At this time, the timer will show the time, velocity and acceleration of gravity of each fixed interval. (At this time, assuming air resistance and Earth's rotation are ignored)

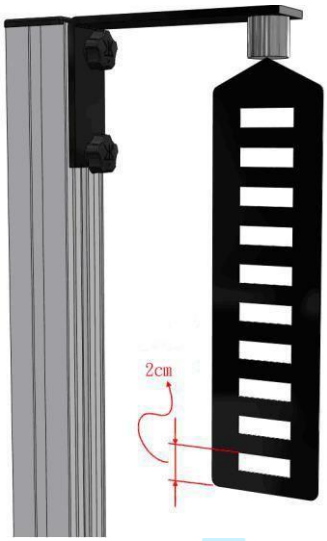
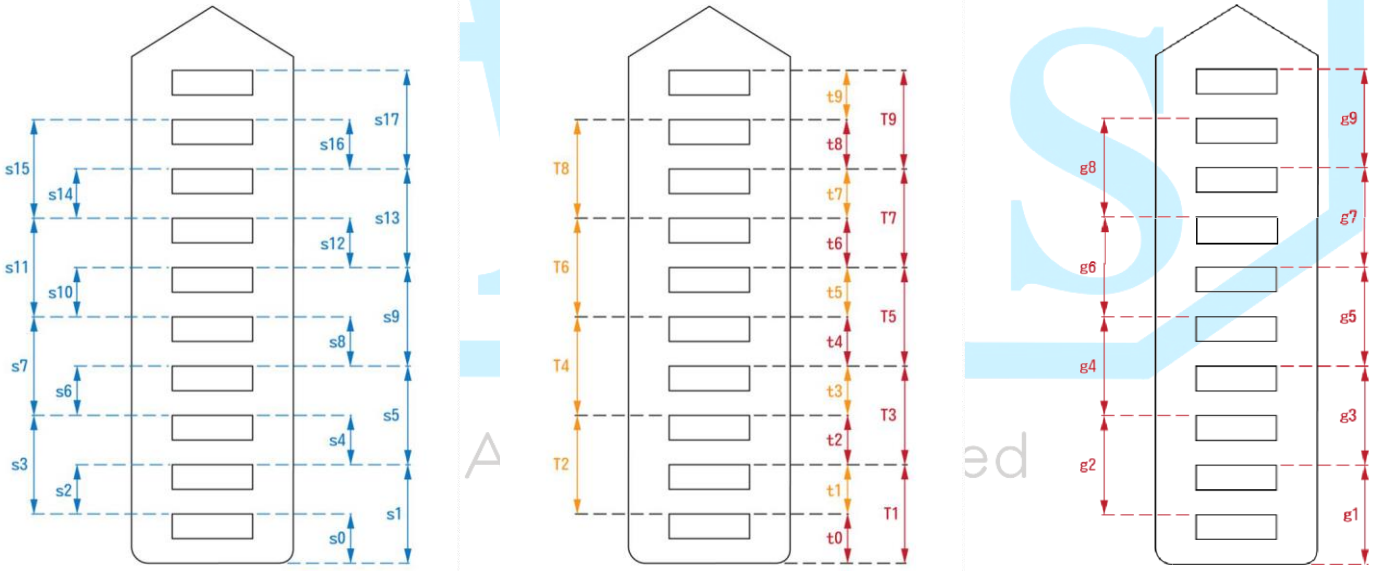


Figure 3

※ The interval is about 2 cm. As shown in Figure 3

Keep track of acceleration of gravity on the next data sheet.



(a) (b) (c)

Department：	Student No.：	Group：	Name：	Date：

Experimental Record:

※$T_n = t_n + t_{n-1}$ n=1，9

※ $g_n = \frac{2(S_N t_{N-1} - S_{N-1} t_N)}{t_{N-1} t_N (t_N - t_{N-1})}$ n=1，9 (cm/s^2)

sub S_N, S_{N-1} into 2, 4

As shown in figure (a), (b) and (c) show, observe that there is a period between intervals, so this equation can be rewritten as:

$$g_n = \frac{2(4t_{n-1} - 2T_n)}{t_{n-1} T_n (T_n - t_{n-1})}$$ n=1，9 (cm/s^2)

Mean Percentage Error=[Σ(｜experimental value g. － theoretical value g.｜/ theoretical value g.) / 9] x100%

Paramet--er / Times	Time (ms)	Fixed Interval(cm)	Theoretical value g.(cm/s^2)	Experimental value g.(cm/s^2)	Percentage Error%
Trial 1	t0	$T_n = t_n + t_{n-1}$	*s0* *2* *s10*	*2* g1	g1 g1
	t1	T1	*s1* *4* *s11*	*4* g2	g2 g2
	t2	T2	*s2* *2* *s12*	*2* g3	g3 g3
	t3	T3	*s3* *4* *s13*	*4* g4	g4 g4
	t4	T4	*s4* *2* *s14*	*2* g5	g5 g5
	t5	T5	*s5* *4* *s15*	*4* g6	g6 g6
	t6	T6	*s6* *2* *s16*	*2* g7	g7 g7
	t	T7	*s7* *4* *s17*	*4* g8	g8 g8

	7													
	t 8		T8		*s8*	*2*	※		g9		g9		g9	
	t 9		T9		*s9*	*4*			g_{av}		g_{av}		g_{av}	

*Estimate to the thousandth digit.

※ *Use the fixed intervals*

Parameter / times	**Time (ms)**	**Fixed Interval(cm)**		**Theoretical value g.(cm/s^2)**			**Experimental value g.(cm/s^2)**			**Percentage Error%**			
Trial 2	t0		$T_n = t_n + t_{n-1}$	*s0*	*2*	*s10*	*2*	g1		g1		g1	
	t1		T1	*s1*	*4*	*s11*	*4*	g2		g2		g2	
	t2		T2	*s2*	*2*	*s12*	*2*	g3		g3		g3	
	t3		T3	*s3*	*4*	*s13*	*4*	g4		g4		g4	
	t4		T4	*s4*	*2*	*s14*	*2*	g5		g5		g5	
	t5		T5	*s5*	*4*	*s15*	*4*	g6		g6		g6	
	t6		T6	*s6*	*2*	*s16*	*2*	g7		g7		g7	
	t7		T7	*s7*	*4*	*s17*	*4*	g8		g8		g8	
	t8		T8	*s8*	*2*	※		g9		g9		g9	
	t9		T9	*s9*	*4*			g_{av}		g_{av}		g_{av}	

* Estimate to the thousandth digit.

※ *Use the fixed intervals*

Parameter / times	Time (ms)		Fixed Interval(cm)		Theoretical value g.(cm/s^2)			Experimental value g.(cm/s^2)			Percentage Error%			
Trial 3	t0		$T_n = t_n + t_{n-1}$		*s0*	*2*	*s10*	*2*	g1		g1		g1	
	t1		T1		*s1*	*4*	*s11*	*4*	g2		g2		g2	
	t2		T2		*s2*	*2*	*s12*	*2*	g3		g3		g3	
	t3		T3		*s3*	*4*	*s13*	*4*	g4		g4		g4	
	t4		T4		*s4*	*2*	*s14*	*2*	g5		g5		g5	
	t5		T5		*s5*	*4*	*s15*	*4*	g6		g6		g6	
	t6		T6		*s6*	*2*	*s16*	*2*	g7		g7		g7	
	t7		T7		*s7*	*4*	*s17*	*4*	g8		g8		g8	
	t8		T8		*s8*	*2*	※		g9		g9		g9	
	t9		T9		*s9*	*4*			g_{av}		g_{av}		g_{av}	

*Estimate to the thousandth digit.

※ *Use the fixed intervals*

Parameter / times	Time (ms)		Fixed Interval(cm)		Theoretical value g.(cm/s^2)			Experimental value g.(cm/s^2)			Percentage Error%			
Trial 4	t0		$T_n = t_n + t_{n-1}$		*s0*	*2*	*s10*	*2*	g1		g1		g1	
	t1		T1		*s1*	*4*	*s11*	*4*	g2		g2		g2	
	t2		T2		*s2*	*2*	*s12*	*2*	g3		g3		g3	
	t3		T3		*s3*	*4*	*s13*	*4*	g4		g4		g4	
	t4		T4		*s4*	*2*	*s14*	*2*	g5		g5		g5	
	t5		T5		*s5*	*4*	*s15*	*4*	g6		g6		g6	
	t6		T6		*s6*	*2*	*s16*	*2*	g7		g7		g7	
	t7		T7		*s7*	*4*	*s17*	*4*	g8		g8		g8	
	t8		T8		*s8*	*2*	※		g9		g9		g9	
	t9		T9		*s9*	*4*			g_{av}		g_{av}		g_{av}	

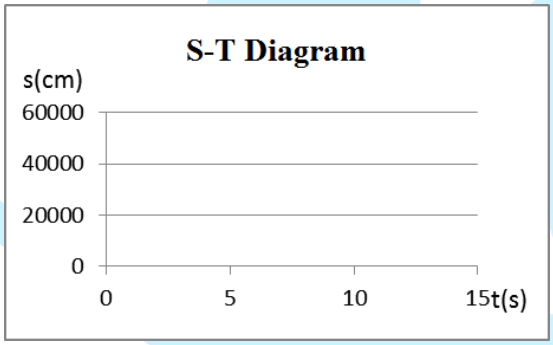
*Estimate to the thousandth digit.

※ *Use the fixed intervals*

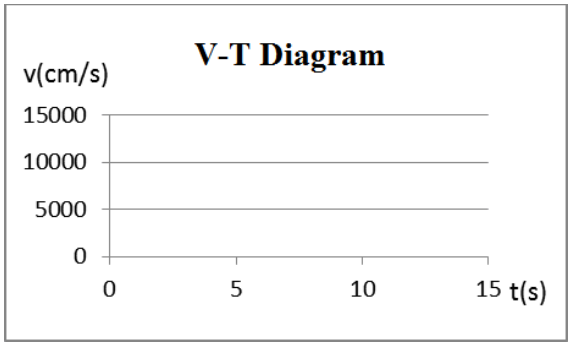
Parameter / Times	Time (ms)	Fixed Interval(cm)		Theoretical value g.(cm/s^2)			Experimental value g.(cm/s^2)			Percentage Error%			
Trial 5	t0		$T_n = t_n + t_{n-1}$	*s0*	*2*	*s10*	*2*	g1		g1		g1	
	t1		T1	*s1*	*4*	*s11*	*4*	g2		g2		g2	
	t2		T2	*s2*	*2*	*s12*	*2*	g3		g3		g3	
	t3		T3	*s3*	*4*	*s13*	*4*	g4		g4		g4	
	t4		T4	*s4*	*2*	*s14*	*2*	g5		g5		g5	
	t5		T5	*s5*	*4*	*s15*	*4*	g6		g6		g6	
	t6		T6	*s6*	*2*	*s16*	*2*	g7		g7		g7	
	t7		T7	*s7*	*4*	*s17*	*4*	g8		g8		g8	
	t8		T8	*s8*	*2*	※		g9		g9		g9	
	t9		T9	*s9*	*4*			g_{av}		g_{av}		g_{av}	

* Estimate to the thousandth digit.

※ *Use the fixed intervals*



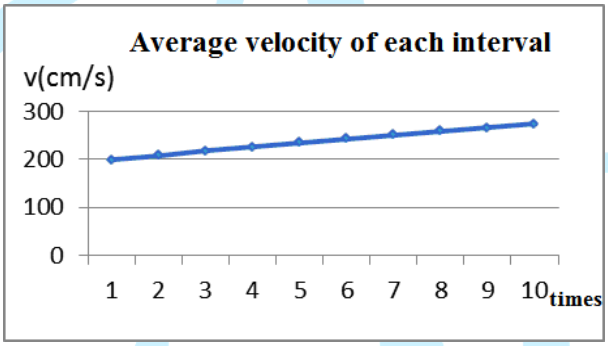
Draw a S-T diagram from any average value of experimental value g.



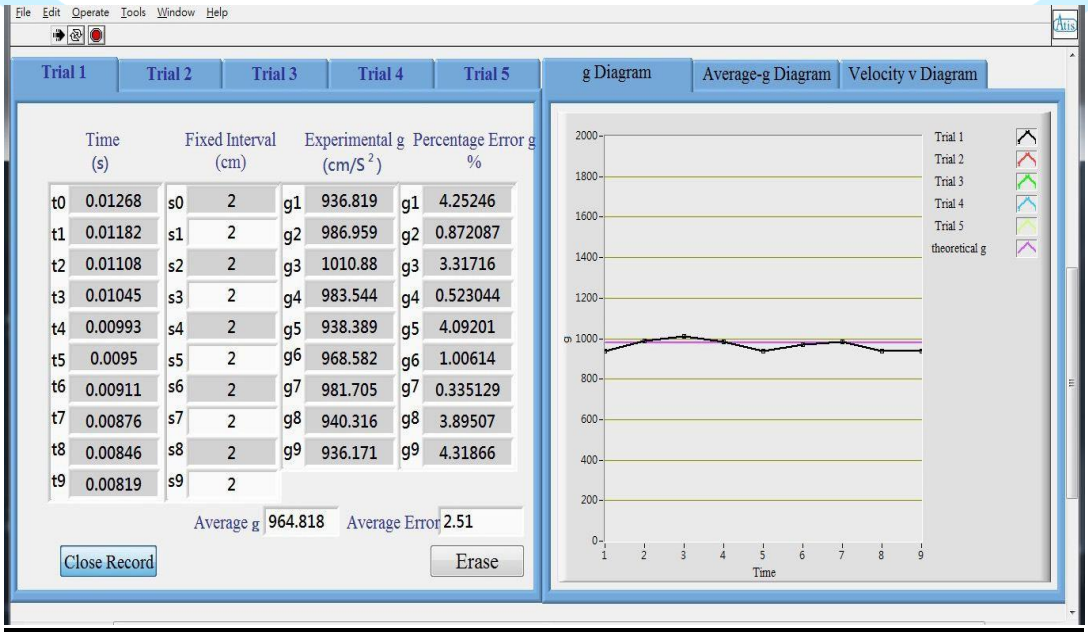
Draw a V-T diagram from any average value of experimental data g.

※V(cm/s)=1000*2(cm)/T(ms)

	Trial 1	Trial2	Trial 3	Trial 4	Trial 5
Interval v_0	198.6097				
Interval v_1	208.1165				
Interval v_2	217.3913				
Interval v_3	225.9887				
Interval v_4	234.7418				
Interval v_5	242.7184				
Interval v_6	250.941				
Interval v_7	258.7322				
Interval v_8	265.9574				
Interval v_9	273.224				



Draw the average V value 【(V=2(cm)/T(ms)】 on the diagram.



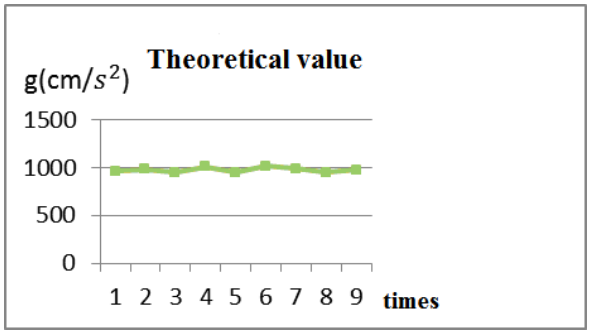
Location	Taipei	Taichung	Tainan	Kaohsiung
Acceleration of gravity (cm/s^2)	978.707	976.516	978.426	977.896

Question and Discussion

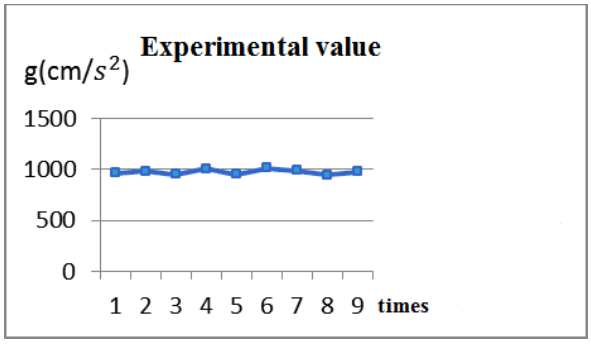
1. Compare the difference between the value from the above form and the theoretical value. Within how much error rate? What kind of factors can affect the measured value of acceleration due to gravity?

Answer: The difference is about 1.3 cm/$\boldsymbol{s^2}$, and the error rate is about 0.02%. There are many factors which can affect the measured value of acceleration due to gravity, such as air resistance, the Earth's rotation and the angle when the fence falls off, etc.

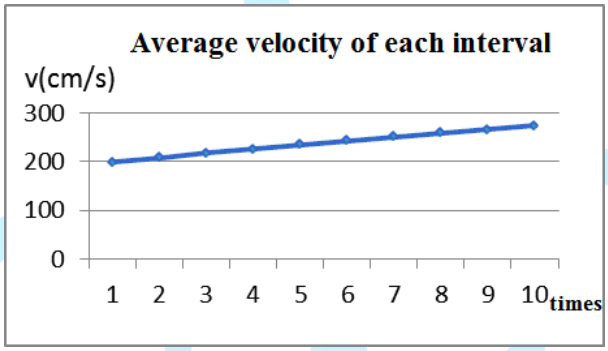
2. Draw the value of acceleration due to gravity on the diagram and compare the difference between theoretical value and experimental value. Are there any other diagrams that it can be compared to?



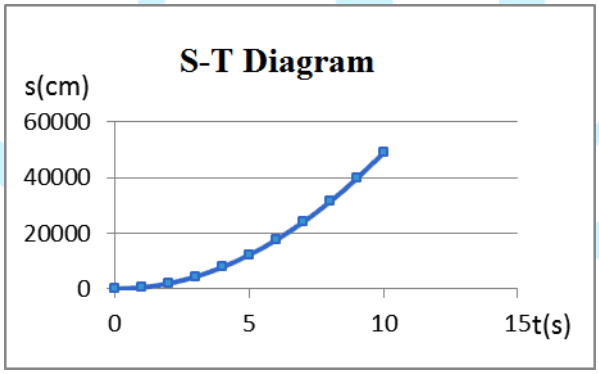
The distribution according to the measured theoretical value.



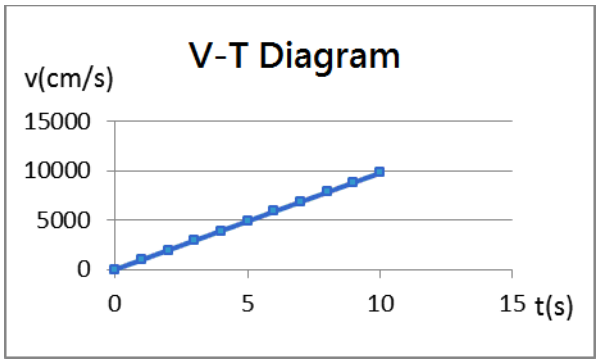
The distribution according to the measured experimental value, so we know both of them match.



Draw the value of the average acceleration on the diagram.



The S-T diagram according to the average measured theoretical value.



The V-T diagram according to the average measured theoretical value.

3. Why are the distances used here fixed at 2 and 4 cm, rather than an arithmetic progression, such as 2,4,6,8?

Answer: We could have used an arithmetic progression to calculate the distances, such as 2, 4, 6, 8, and 10….etc. Relatively, the value of time would have to be raised, too, which would make the calculation more complicated. So, we use the fixed numbers for simple calculation. In conclusion, we know that we can't just memorize physics formula; we also have to know how to use it flexibly.

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