Prepared by Leong Yee Pak

DESIGN QUESTIONS

Below are some suggestions on how to go about in designing an experiment. Understand and remember the various instrument used for measuring the quantities, the methods used to produce them and the way to vary them.

Guide for Design Questions

- Identify the variables: the independent variable, the dependent variable, and any variables or factors to be kept constant.
- Draw a labelled diagram to show the experimental set up.
- Ask yourself these questions:

  (a) For independent variable:
  (i) How to produce the variable?
  (ii) how to vary the variable?
  (iii) how to measure the variable?

  (b) For dependent variable:
  (i) How to produce the variable?
  (ii) How to measure the variable?
  (c) What are the variables / factors to be kept constant?

How to monitor them so that they are kept constant?

  (d) What are the safety precautions?
  (e) How the results are to be analysed?
  (f) Further good design / experimental features?

E.g. Any precautions to be taken to improve the accuracy of the experiment, any comment on the difficulties of the experiment, suggestion on how the table to be drawn and the graph to be plotted.

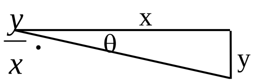
The tables below give suggestions how to measure certain variables. The list given is not exhaustive.

	Measurement	**Instrument / method**
1	(a) Length, distance (b) Small length (c) Diameter of a wire, tube (d) External diameter of a tube (e) Internal diameter of a tube	(a) Metre rule (b) Vernier scale, travelling microscope (c) Micrometer screw gauge (measure 5 times in different places and direction, then take average) (d)(i) Micrometer screw gauge (ii) travelling microscope. (Measure in a few different directions and take average.) (e) (i) Travelling microscope. (Measure in a few different directions and take average.)  (ii) Introduce a mercury column, measure length of column, determine mass of mercury column. Then $M = \rho V$, $M = \rho\,(\pi r^2)\,l$ where $\rho = 13.6 \times 10^3$ kg m^{-3}
2	(a) Large time interval (b) Short time interval (c) To measure short time interval of a moving body between 2 different positions	(a) Stop watch (b) (i) Stroboscopic photography (camera, stroboscope and background scale. The time for each photograph is given by 1 / *f* where *f* is the frequency of the stroboscope) (ii) c.r.o. (cathode-ray oscilloscope) with calibrated time base on. Distance between 2 signals = *d*. Calibrated time base = *T* per unit length. The time interval between the 2 signals = *Td*. (c)(i) Stroboscopic photography (ii) Two light-gates + photo-cells & electronic timer.

3	Velocity / terminal velocity, acceleration	(i) Stroboscopic photography (camera, stroboscope and background scale). Calculate v using formula $\underline{v = s / t}$ (ii) Two light-gates + photocells + electronic timer. Time interval is recorded when the lights reaching the photocells are interrupted by the moving body. Distance between light-gates measured with metre rule. Then calculate the speed v using $\underline{v = s / t}$.
4	(a) Temperature (b) Fast changing temperature (c) Temperature in remote area (d) Temperature of a small body	(a)(i) Mercury-in-glass thermometer (ii) thermocouple thermometers (b) Thermocouple thermometer (c) Thermocouple thermometer (d) Thermocouple thermometer
5	(a) Current (b) Small current	(a) Ammeter in series (b) Milli-ammeter in series, micro-ammeter in series
6	(a) Potential difference / e.m.f. (b) small e.m.f	(a) (i) Voltmeter in parallel, (ii) c.r.o. (b) milli-ammeter, micro-voltmeter
7	Resistance	(i) Voltmeter in parallel for measuring V, ammeter in series for measuring I, then $R = V/I$ (ii) Ohmmeter
8	Magnetic flux density (magnetic filed strength)	(i) Calibrated Hall probe (surface of Hall probe must be perpendicular to the magnetic field, placed in the same positions in the centre of field, check for zero error reading on meter) (ii) Search coil + galvanometer (plane of search coil perpendicular to the magnetic field and then removed to far away. Repeat with the coil rotated 180^o. Place coil in the same positions in the centre of field) Note: Remove all magnetic materials near apparatus

9	To measure electric field strength	Measure the p.d. *V* across the parallel plates using voltmeter. Measure separation *d* between the 2 plates using a travelling microscope. Then calculate *E* using $E = \frac{V}{d}$.
10	Force, tension	Newton meter. Read from calibrated slotted mass.
11	Sound intensity	Microphone + c.r.o. Measure height of vertical trace on the screen of c.r.o. with time-base off. (Cover with absorbent material to absorb unwanted sound from other sources. Use cardboard tube to guide the direction of sound. Perform experiment in a quiet room)
12	Frequency of sound	(i) Read value of *f* from calibrated signal generator, (ii) Microphone + c.r.o. with calibrated time-base on. Count the number *N* of oscillations of the waveform seen on screen. Calculate the time taken *t* from the time-base setting for *N* oscillations. Calculate *f* using the formula $f = N/t$
13	Wavelength of sound	Produce stationary sound wave using a signal generator + speaker + a large board as a reflector. Determine positions of nodes or antinodes with microphone + c.r.o. Measure distance between nodes or antinodes (= *d*). $\frac{\lambda}{2} = d$. Hence calculate λ using $\lambda = 2d$
14	Speed of sound	Read value of frequency *f* from calibrated signal generator. Determine λ using stationary wave method. Then calculate *v* using $v = f\lambda$
15	Speed of ripple waves on surface of water	Use $v = f\lambda$. Determine frequency of vibrator with counter attached. Frequency of waves = frequency of vibrator, *f*. Use parallel lights to project image of ripple waves on a screen on floor. Use a stroboscope to 'freeze' the images of the ripple waves, then measure the wavelength λ.

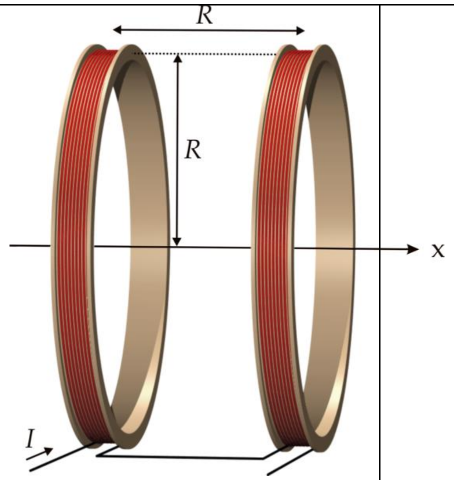
16	mass	(i) Top pan balance (ii) Measure volume with measuring cylinder if density is known, then calculate M using $M = \rho V$
17	Volume of liquid	Measuring cylinder
18	Light intensity	(i) Light-meter, or photodiode with milli-ammeter. (ii) Light-dependent resistor (LDR) + ohmmeter. As intensity of light increases, resistance of LDR decreases. LDR to be calibrated earlier. Note: Perform experiment in a dark room, or cover with sheets of matt black card.
19	Humidity	Hygrometer
20	(a) Density of liquid (b) Density of solid	(i) hydrometer (ii) Measure mass using a balance, measure volume using measuring cylinder. Then calculate density using $\rho = \frac{M}{V}$ Measure mass using a balance, immerse solid into an eureka can, and volume of water displaced measured with a measuring cylinder. Then calculate density using $\rho = \frac{M}{V}$
21	Count rate of radioactive source	Geiger-Muller tube + scaler OR Geiger-Muller tube + ratemeter. True count-rate = reading - background count-rate.
22	Range of α-particles in air	First note the background count rate. Then move G-M (Geiger Muller) tube from source until reading = background count rate. Measure distance of G-M tube from source with metre rule.
23	Input power of motor	Measure V with voltmeter in parallel. Measure I with ammeter in series. Then calculate power using $P = VI$
24	(a) Output power of motor	Use motor to raise a load of mass m. Measure height h of load raised with metre rule. Measure time taken t with a stop watch. Output power =

	(b) Output power of a source	Work done / time $= \frac{mgh}{t}$ Connect an ammeter and a resistor in series. Then connect a voltmeter in parallel across the voltmeter. Power output $P = VI$
25	Electrical power dissipated in a resistor	Use $P = VI$, $P = I^2R$, $P = \frac{V^2}{R}$. Measure V, I or R using the voltmeter, ammeter or ohmmeter.
26	Pressure	Pressure gauge (Bourdon gauge)
27	(a) Angle (b) Angle in inaccessible area	Protractor Projection by light on a screen, then measure with protractor OR use $\tan\theta = \frac{y}{x}$.  Measure the linear displacement y and the distance x. Then calculate θ using $\tan\theta = \frac{y}{x}$.

The table below gives suggestions how to manipulate or vary certain variables. The list is not exhaustive.

	Manipulation of variables	**Instrument / Procedure**
1	To vary temperature of liquid	Immersion heater + stirrer
2	To keep temperature constant	(i) Thermostat connected in series with heater (thermostat must be in the substance whose temperature is to be kept constant) (ii) Water bath
3	To produce p.d. / to supply current	Power supply unit, battery
4	To vary current or p.d.	(i) connect to different output of a variable power supply unit (psu) (ii) potential divider (iii) rheostat
5	To vary p.d. when current is zero or negligible	(i) Connect to variable power supply (ii) Use a potential divider (for low p.d. only. Can be dangerous if p.d. is high)

6	To produce signal of audio frequencies	Signal generator
7	To produce vibration in a stretched string	Signal generator + vibrator
8	To produce sound of constant frequency	Signal generator + speaker
9	To produce vibration in a tube opened at one end / both ends	Tuning fork with known frequency
10	(a) To produce resonance in stretched string (b) To produce resonance in a tube closed at one end (long tube partially immersed in water)	Signal generator + vibrator. Vary frequency f of signal from signal generator from zero until $f = f_0$, natural frequency of the stretched string. Maximum amplitude of vibration is seen with eyes. Resonance also occurs at frequencies at 1st overtone, 2nd overtone etc Vary length of tube above water, until maximum sound is heard. (Frequency of tuning fork = natural frequency of tube when resonance occurs.)
11	To produce humidity	Bucket of water + small immersion heater in an enclosed space.
12	To produce a narrow beam of light	(i) laser pen. (ii) ray box with slit and a converging lens
13	To produce tension / to vary load	A set of slotted masses with a mass holder (with a pulley if string is horizontal). Tension T is calculate using T = mg
14	To vary pressure	Vacuum pump
15	To reduce friction	Pulley, wheels, rollers, grease, oil
16	To produce uniform magnetic field	(i) Use Helmholtz coils: 2 large coaxial parallel coils of equal radius, separated by a distance equal to the radius of the coils, carrying equal currents in the correct directions, so that the poles facing each other are opposite in polarities. (ii) 2 permanent magnets with large flat poles facing each other. The north pole and the south pole are facing each other.

		
17	To vary magnetic field	(i) Change the current in the Helmholtz coils (ii) Change the distance between the poles of the 2 large permanent magnets
18	To produce uniform electric field	Use 2 large parallel plates separated at a short distance. Supplied p.d. across the 2 plates.
19	To vary electric field strength	Vary the V, keeping d constant OR Vary d, keeping V constant.

Safety Precautions

1	Wire under tension may snap and produce a back whip, hot liquid may splash up	Put on protective goggles, use safety screen
2	To handle hot wire, or hot object	Use gloves
3	Heavy load hanging on retort stand	Clamp the retort stand using a G-clamp
4	Hot oil or liquid, or dangerous chemicals	Use safety screen
5	Heavy load may fall and hurt feet, or damage floor	Place a bucket of sand under the load
6	High tension supply (high voltage)	Use rubber-coated wire for connections, put on dry rubber shoes, stand on a dry rubber matt on dry floor
7	High pressure or low pressure At high pressure, container may explode. At low pressure, container may implode.	Wall of container has to be strong to withstand the high/low pressure Use safety screen.
8	To handle radioactive materials	Use tongs, keep source at an arm's length, do not direct source at others or to oneself, wash hands with soap after use, keep source in lead box after use
9	To handle laser beam	Do not point laser beam at own eyes or others' eye

Example

A student suggests that the velocity v of sound and the temperature T of the air are related by the equation

$$v = k\sqrt{T}$$

Design a laboratory experiment to find out whether the student is correct.

First ask yourself these questions:

What are the independent variable, the dependent variable and other variables to be kept constant?
How to vary temperature? How to measure temperature?
How to produce the sound? How to measure the speed of sound?
What are the methods to keep the fixed variables constant?
How do you analyse your results?
What are the safety precautions (if any) to be taken?
What are the good experimental features to improve the experiment? Any difficulty you may encounter?

Follow the format below in your answer:

A Defining the problem

(i) What is the independent variable?
(ii) What is the dependent variable?
(iii) What is the variable(s) to be kept constant?

B Methods of data collection

(i) Workable arrangement (well-labelled diagram)
(ii) Method of varying and measuring the independent variable
(iii) Method of measuring the dependent variable

C Method of analysis

(i) What graph to be plotted (Deduce from the relationship given, if any.
If the relationship is given as $y = ax^n$, and you are required to find a and n, then plot a graph
of log y against log x.)
(ii) Make deduction from the graph

D Safety consideration

State the safety precaution, if any.

E Additional details

(i) Method of controlling the variables
(ii) Ways to improve the experiment
(iii) Difficulties and limitations of the experiment

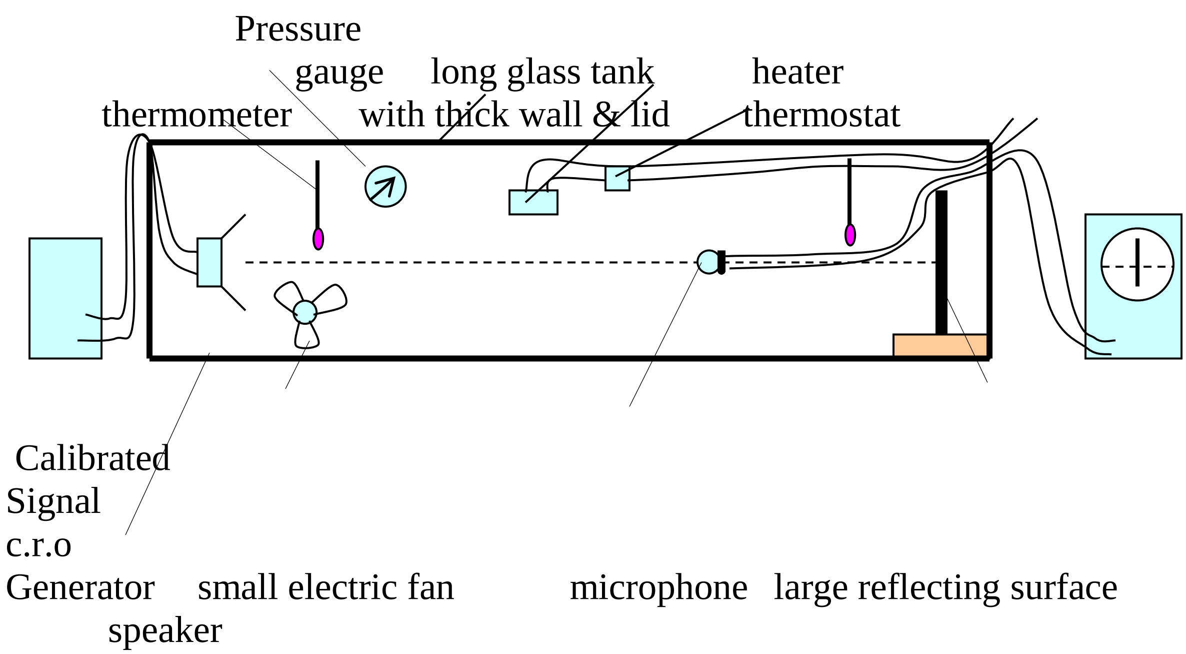
Answers to the question above

A Defining the problem

Temperature *T* of the air is the independent variable
Velocity *v* of the sound is the dependent variable.
Variables to be kept constant are pressure of the air, frequency of the sound

B. Methods of data collection / procedure

(i) Workable arrangement (Always draw a labelled diagram to illustrate)



The whole experiment is performed in a large glass tank with thick wall and a lid.

The sound is produced by connecting a speaker to a signal generator. The frequency of the signal generator is set at about 3000 Hz.

(ii) Method of varying temperature T of the air.
The temperature of the air is varied by the heater. The temperature can be kept steady by the thermostat. The temperature is measured by thermometers.

Start the experiment at room temperature and determine the speed of sound.

(iii) Method of measuring the speed v of sound.
The speed of sound is determined as follows.
Stationary sound wave is produced by placing a large reflecting surface facing directly the speaker at a distance away as shown. The positions of the nodes in the stationary wave are detected by a microphone connected to a c.r.o. with time base off. A node is detected when the vertical trace on the c.r.o. screen is the shortest. The microphone is moved along the dotted line joining the speaker and the reflecting surface as shown. As the microphone is moved along the dotted line, a number of nodes are detected. Let it be N. The distance x for N nodes is measured with a metre rule. Calculate the distance between nodes using the relationship $d = \frac{x}{N}$. The wavelength of the sound is found using $\lambda = 2d = 2\frac{x}{N}$.
The frequency of the sound is read from the calibrated signal generator. The velocity of sound is then calculated using the relationship $v = f\lambda$.

The experiment is repeated by varying the temperature of the air. The speed of sound is determined for different values of the temperature of the air. The temperature is changed by adjusting the thermostat with the heater.

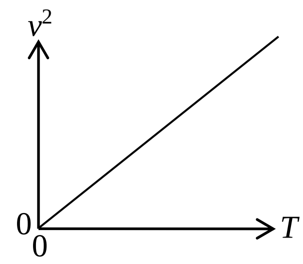
C Method of analysis
From the equation $v = k\sqrt{T}$, hence $v^2 = k^2\, T$.

The results are recorded as below.

Frequency of sound (as read from the signal generator) = f

Temperature, T / °C	wavelength of sound λ_1/ m	λ_2 / m	λ_{av} /m	velocity, v / ms^{-1} ($v = f\lambda$)	v^2 / m^{2}s^{-2}

A graph of v^2 is plotted against T.



Deduction
If the graph is a straight line passing through the origin, the equation is correct.

D Additional details
Other experimental features are as follows:

- The distance between the speaker and the reflecting surface is kept constant.
- The temperature of the air is made uniform by blowing the air using a small electric fan. When readings are taken, the fan is switched off.
- To ensure that the temperature is uniform, the temperature is measured at a few places by different thermometers.
- The pressure of the air is kept constant. The pressure is measured by a Bourdon gauge. (Note: the speed of sound does not depend on pressure, but we assume that we do not know it)
- During each measurement of the speed of sound, the temperature of the air is kept steady by the thermostat.
- The experiment is to be done in a quiet room.
- The walls of the glass tank are to be covered with sound absorbing material, so that there is no sound reflected from the walls.