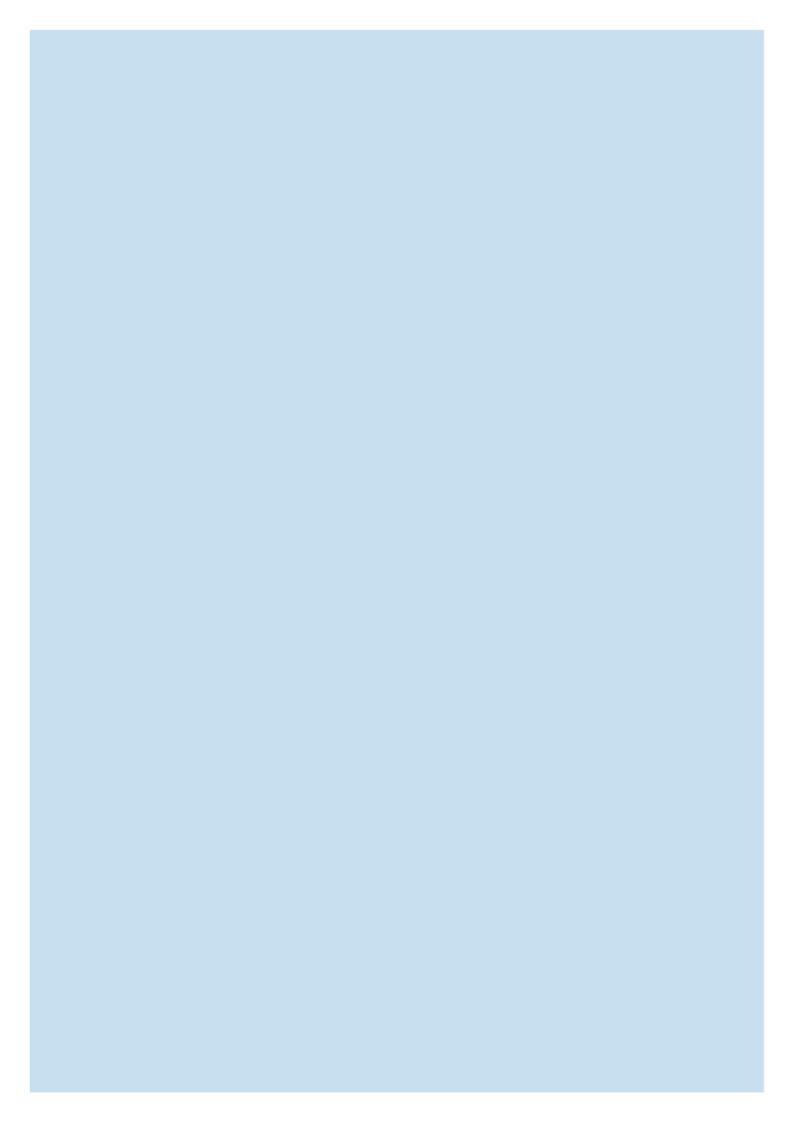
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Student workbook

MSL922001

Record and present data

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**TAFE NSW would like to pay our respect and acknowledge Aboriginal and Torres Strait Islander Peoples as the Traditional Custodians of the Land, Rivers and Sea. We acknowledge and pay our respect to the Elders, both past and present of all Nations.**

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Innovative Manufacturing, Robotics and Science

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|  | **Practice activity**  Learning activities are the tasks and exercises that assist you in gaining a clear understanding of the content in this workbook. It is important for you to undertake these activities, as they will enhance your learning.  Activities can be used to prepare you for assessments. Refer to the assessments before you commence so that you are aware which activities will assist you in completing your assessments. |
|  | **Collaboration**  Whether you discuss your learning in an online forum or in a face-to-face environment discussions, allow you to create and consolidate new meaningful knowledge. |
|  | **Self-check**  A self-check is an activity that allows you to assess your own learning progress. It is an opportunity to determine the levels of your learning and to identify areas for improvement. |
|  | **Readings (Required and suggested)**  The required reading is referred to throughout this Student workbook. You will need the required text for readings and activities.  The suggested reading is quoted in the Student workbook, however you do not need a copy of this text to complete the learning. The suggested reading provides supplementary information that may assist you in completing the unit. |

Topic 1

Introduction

# Introduction

This unit of competency covers the ability to record and store data, perform simple calculations of scientific quantities and present information in tables and graphs. The unit of competency requires personnel to solve predictable problems using clear information or known solutions. Where alternatives exist, they are limited or apparent.

This unit of competency is applicable to production operators, field assistants and laboratory assistants working in all industry sectors.

While no specific licensing or certification requirements apply to this unit at the time of publication, laboratory operations are governed by relevant legislation, regulations and/or external accreditation requirements.

## In the workplace

One question students often ask is ‘how is this used in the workplace?’, so before we begin, let us examine how we record and present data in the workplace.

### Construction materials laboratory

*A laboratory assistant is given 20 soil samples and asked to test their moisture content by weighing each sample, placing them in an oven for 24 hours and then reweighing them.*

*The assistant performs the tests in accordance with the standard method and then calculates the % water content by dividing the weight loss by the wet weight and multiplying by 100. They then check the results.*

*After entering the results into the laboratory information management system (LIMS), they notice that they are consistently less than the previous results recorded for soils at the same site.*

*The assistant reports the discrepancy to the supervisor who checks whether the oven was operated at the required temperature. The supervisor then discovers that the assistant has calculated the moisture content by dividing the weight loss by the wet weight instead of the dry weight.*

*The assistant recalculates the moisture content for the 20 samples and notes that the results are now consistent with previous results.*

The data collected in this example included sample related data, raw data from testing and measuring and even created new data simply by entering data into the LIMS. This example also highlights the use of standard methods and good communication. What could have been the consequence if procedure was not followed?

### Manufacturing processes

*On Friday, a laboratory assistant performs the routine set of temperature, pressure and humidity measurements at 10 sites in a refinery.*

*They enter the data on a prepared data sheet that also contains the data recorded for the previous days of that week. The assistant checks the data for any significant variations to that recorded previously.*

*They notice that for site #5, the temperature reading is 250°C which is 100°C below the expected value. The assistant repeats the measurement and gets the same result. After returning to the laboratory, the assistant enters the data into the LIMS and reports the odd result to their supervisor.*

*The supervisor contacts the site manager and finds out that the pipeline at site #5 has been isolated as part of unscheduled maintenance in that part of the site.*

The data collected here included raw measurements and location related data. The use of standard methods, or forms in this case, as well as communication are repeated daily throughout laboratory work.

## Following workplace procedures

When we do work in a lab, the work is usually *standard* work, meaning that it is the type of work that is so routinely performed that the organisation has written a work instruction on how to do it.

One common problem is what these instructions are called, as different industries (and even different companies in the same industry) can use any name they want when designing these instructions. These days there are usually two different types of instruction; *general instructions* and *risk managed instructions*. The only difference between the two is that the process of *hazard identification, risk assessment and control* has been performed on a general instruction to create a risk managed instruction.

Examples of the names used for *general instructions* include;

* Standard Operating Procedures (SOP, one of the oldest terms)
* Written Work Procedure
* Work Instructions (or variants of)

Examples of the names for *risk managed* instructions include;

* Safe Work Method Statements (used in the construction and related industries)
* Job Safety/Environment Analysis (JSA/JSEA)
* Task Hazard Analysis (THA)

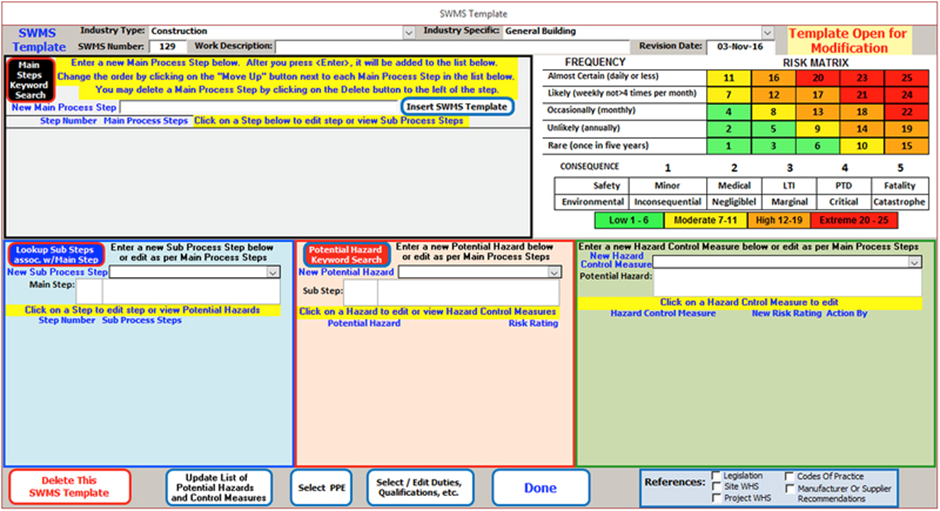


Figure 1.1 – Example of a Safe Work Method Statement. © TAFE NSW

Examples of the types of work that procedures would cover include;

**Administration related**

* Induction and orientationprocedures
* Customer survey procedures
* Staff training procedures

**Sample related**

* Sample receipt and condition
* Sample collection procedures
* Sample transportation procedures

**Data related**

* Verification of data quality
* Rectifying errors in data
* Managing data (data entry, storage, retrieval, communication and security)

**Analysis related**

* Analytical procedures
* Results calculation procedures
* Statistical analysis procedures
* Results validation procedures

**Maintenance related**

* Equipment installation procedures
* Equipment decommission procedures
* Equipment repair procedures
* Decontaminations procedures

## Maintaining workplace confidentiality standards

### Confidentiality

Confidentiality is the protection of personal information. Confidentiality means keeping a client’s information between you and the client, and not telling others including co-workers, friends, family, etc. Examples of maintaining confidentiality include:

* individual files are locked and secured
* support workers do not tell other people what is in a client’s file unless they have permission from the client
* information about clients is not told to people who do not need to know
* clients’ details are not discussed without their consent

The types of information that is considered confidential can include:

* name, date of birth, age, sex and address
* current contact details of family, guardian etc
* bank details
* medical history or records
* personal care issues
* service records and file progress notes
* individual personal plans
* assessments or reports
* guardianship orders
* incoming or outgoing personal correspondence.

Other information relating to ethical or racial origin, political opinions, religious or philosophical beliefs, health or sexual lifestyle should also be considered confidential. Always check with the most current legislation or policy to establish a comprehensive list for your workplace.

There is, however, no such thing as absolute confidentiality in any industry.

As an employee, there will be times when you could be faced with some personal difficulties regarding confidentiality, so you need to be aware of the limits to the confidentiality that you are offering. There are several instances where total confidentiality is either impossible, undesirable or illegal. These include:

* cases where the law requires disclosure of information which will be
* if a worker is subpoenaed to present information in a court of law
* the need to keep records
* when working in conjunction with other professionals for the same client
* the requirements of professional supervision, training, workshops or seminars.

When working with other professionals it is good practice to obtain the written consent of the client before exchanging information.

To ensure confidentiality, employees should only access confidential information for work that is covered by their job description and the policies and procedures of the organisation. They should only disclose information to other parties where a client (or co-worker in relation to their personal information) has consented to the release of the information or where disclosure is required or mandated by legislation due to indications of risk of harm. Further workers need to ensure that any information that is collected is securely stored and disposed of.

### Confidentiality and security

There is no such thing as absolute confidentiality in our industry—especially when it comes to recording information about client contact or observations about clients.

There may be people authorised in your organisation, or working in other services that are authorised to see information about clients. As well, it is every client’s right to see the information recorded about them if they wish to do so. It is not; however, any client’s right to see information recorded about another person.

It follows that it is essential that all information and documents that are confidential are kept secure. Upholding confidentiality and security involves keeping information and documents in a place that can’t be easily accessed by non-authorised people.

### Storage of records

All organisations need to ensure that all records are correctly stored in line with current legal requirements. Record storage must be secured in a place where there is no possibility that they could be damaged. The storage system must be easily accessed by authorised workers. Secure spaces are:

* rooms that are locked
* filing cabinets that are locked
* drawers that are locked
* passwords on computers.

Ways of maintaining confidentiality are to:

* talk about clients in a private and soundproof place
* not use client’s names
* only talk about clients to relevant people
* keep communication logbooks in a drawer or on a desk away from visitors
* keep staff files in a locked cabinet in the manager’s or coordinator’s office
* use reference numbers when recording information about clients on a database

### Destruction of records

Most records are kept for as long as they are in use by the organisation or for the length of time that the client receives a service. In some cases legislation requires the archiving of client files for 7 years and each organisation needs to be familiar with the legislation as it applies to their service and client group. Any confidential information must be shredded before it is sent for recycling.

### Legislation governing confidentiality

All workers need to be aware that there are State and Federal laws that cover confidentiality. The following Acts relate to privacy and confidentiality of clients:

#### Health Administration Act 1982

This Act covers any information that is provided or recorded within the health system. Basically, information cannot be disclosed, without the consent of the person to whom the information relates or for the purpose of legal proceedings, such as a court order or subpoena that allows access to health information on a client.

#### The Public Health Act 2010

This Act also relates to disclosure of information without consent. The most important confidentiality provision of this Act is the part that deals specifically with HIV/AIDS related information. Under this Act, this means two things:

#### Health Records and Information Privacy Act 2002

This Act is designed to protect the privacy of an individual’s health information, enable individuals to gain access to their health information and provide an accessible framework for resolution of complaints regarding the handling of health information

#### Privacy and Personal Information Protection Act 1998 (NSW)

This Act consists of internationally accepted privacy principles dealing separately with collection, storage, use and disclosure of personal information. One of the key principles relates to accessibility of information, stipulating that agencies must allow access to a client’s personal information without reasonable delay and expense, when it is requested.

## Common souces of data and their workflow

Although every laboratory is different, there are workflows that generally apply. The workflow presented below is scalable to large companies and small, and can be used internally or externally relative to the organisation.

### Analytical problems

The most important aspect of any analysis is to ensure that it will provide useful and reliable data on the material being analysed. The laboratory technician must often communicate with other scientists and non-scientists to establish things like;

* the amount and quality of the information required
* the time-scale for the work to be completed
* budget

It is essential for the laboratory technician to have an appreciation of the objectives of the analysis and an understanding of the capabilities of the various analytical techniques at their disposal so they can select or develop the most appropriate and cost-effective method.

### Analytical procedures

The stages or steps in an overall analytical procedure can be summarized as follows;

1. **Definition of the work**

Analytical information and level of accuracy required

1. **Choice of technique and method**

Selection of the best technique for the required analysis

1. **Sampling**

Selection of a small sample of the material to be analysed.

1. **Sample pre-treatment or conditioning**

Conversion of the sample into a form suitable for detecting or measuring.

1. **Qualitative/quantitative analysis**

Tests on the sample under specified and controlled conditions

1. **Preparation of report or certificate of analysis**

Summary of the analytical procedure, the results and their statistical assessment.

The topics in this workbook will help you understand the basis of measurement, managing data to minimise and rectify errors, calculating scientific quantities and presenting and interpreting data.

Topic 2

Record and check data

# Record and check data

## Introduction

In the workplace, measurements are seldom written down haphazardly on a piece of paper. They are usually recorded in the form of a table, graph or chart. In this way, the information can be clearly read and understood at a future date. A collection of measurements is often referred to as data. We will be using this term in this section of the learning guide.

In many workplaces, measurements are recorded in result sheets that are produced and photocopied by the workplace. If this is the case for your workplace, successfully using such result sheets will form part of your assessment.

In some areas of scientific work, standard result sheets are not used. Instead, the measurements are recorded in a table. In this section you will learn how to construct and use such a table.

Measurements are sometimes taken to see if there is a relationship between two quantities. In this case the measurements are plotted on a graph. This gives a visual representation of the data that is much more easily interpreted than columns of data. In this unit you will learn how to present measurements in the form of a graph.

## Entering data into information system or record sheets

The word data refers to the results of tests, measurements or analyses. Data is obtained when you calibrate instruments and when you sample or test products. Data can be:

* Quantitative - data are measurements and are written as numbers.
* Qualitative - data are descriptions of samples.

Data must be processed, presented and stored so that it can be found when it is needed. For example, the data obtained from swabbing and plating equipment and surfaces around a plant is recorded and stored. The results can then be compared from time to time to see if there is any change in workplace and product hygiene. If the results showed an increase in bacteria, then urgent action may be required.

**Example:**

If you are not sure about the data recording processes at your workplace, you must ask before attempting to enter or retrieve information into or from the enterprise system. Incorrect data is worse than no data as it is incorrect and misleading. Imagine what would happen in a busy metropolitan hospital if patient data was mixed up!

### Coding data

A sample is worthless unless its origin and/or history are recorded. The origin of a sample is the place and time where it was taken, such as a particular work area or batch.

The history of a sample is a record of how the sample was taken and what has been done to test it. Samples must be carefully labelled to avoid confusion and to make sure that the sample can always be linked to the place and time where it was taken.

All data obtained must be coded. This means that the data must be identified in some way so that it is linked to its origin and history. For example, if you have obtained data from testing wine bottles, when you record that data you must identify the crates or batch that each sample was obtained from.

This means that every sample in a plant must be coded so that the data obtained from it can be identified with the place that the sample was taken from. The sample code must be with the sample at all times, on its label, so that it will not get mixed up with the other samples taken at different locations.

The same applies to instruments like thermometers that are calibrated. These are coded so that accurate calibration records can be kept. Careful coding will give you an audit trail. An audit trail is a way that you can trace any sample or result back to its source.

This is particularly important for two reasons:

1. In a quality system, you must be able to prove the reliability of your test results by being able to trace back from the result to find out exactly how tests were done and how the samples were collected.

2. If there is a problem with a result, it may be necessary to take some form of corrective action. For example:

* If there was a food poisoning outbreak caused by salami, it would be necessary to know exactly which batch of salami caused the problem.
* If a customer questioned the reliability of the results of your testing, you must be able to show exactly how the results were obtained, what equipment was used and whether it was in proper working order at the time.

### Recording data

All data must be reliably recorded in a way that allows other people to find it and read it at a later time. It can be recorded on paper records or electronically using a computer.

Data obtained from calibration, sampling and testing must be recorded with at least the following information:

* the name of the sample, test or item calibrated and a code that uniquely identifies it
* the name of the person responsible for the sampling, testing or calibration
* the time and/or date of when the sampling, testing or calibration was done
* the results and whether the product or item being tested passed or failed

If a product or item of equipment fails a test, this must be noted. You should also start the appropriate procedures. For example, if an instrument is calibrated and found not to meet tolerances (acceptable range) and cannot be adjusted, it must be marked as defective and not used until it has been repaired or replaced.

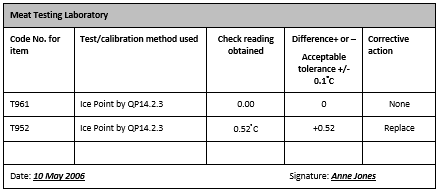
Test results may be recorded using hand written entries on a result sheet or form. This sheet or form is prepared as part of the plant Quality Plan and will be similar to the form shown below. From there, the results may be transcribed into a computer database from which printed reports or statistical charts can be generated. In some large plants, where the testing apparatus is linked to a central computer, the results are automatically logged as soon as the measurements are taken.

Figure 2.1 - Sample equipment check form. © TAFE NSW

In the first column you will find that each thermometer is identified by its own code number. The check report shows which thermometers can be used reliably and which cannot.

In the second column of the table you will see that the check method is identified by a code. The code number, in this case, tells you that the check was done using the method in the company Quality Plan section 14.2.3. It should be possible for another person to repeat the check in exactly the same way by following the method that has been identified by its code.

Other people need to rely on the data that you record. If they cannot easily read your writing, they will make mistakes that can cost your business time and money. It is very important to write clearly. Print if you need to. The reliability of your quality assurance system, customer satisfaction and public safety, depend on your care in recording data.

|  |  |
| --- | --- |
| Practice activity icon | Activity 2.1 – Workplace results form |

1. *Obtain a copy of the form that is used in your laboratory to record the results of a specific test that you are familiar with.*
2. *Ask your trainer/supervisor to show you how to write down the results and the meaning of the codes that are used to identify the samples and results.*
3. *Explain how the data you have recorded is coded. That is, what features on the form identify the origin and history of the samples, equipment or environment tested?*

## Check data to identify transcription errors or atypical entries

It is critical that data is recorded in such a way that it clearly links to the relevant samples, sampling points, production batches or processing records.

Similarly it is important that the data recorded is correct. There are a number of common errors that arise with the handling of data and these include:

### Transcription errors

This is where the data is not written down correctly and often involves transposition of numerals or numbers in a long list.

For example, transposition of numerals writing 1.93% w/v, when the correct result was 1.39% w/v.

For example, transposition of words in a list:

**List should be: But it is written:**

Mr X Negative Mr X Positive

Mrs Y Negative Mrs Y Positive

Ms P Positive Ms P Negative

Transcription errors are very common. People often put a lot of time and effort into getting their measurement right and very little effort into checking for transcription errors. Transcription errors often lead to significantly larger errors than measurement errors. You should ensure that someone else checks your work because it is often difficult to see your own mistakes. Checking other people’s work should be taken seriously and not taken on trust just because the other person usually gets it right. The checker always assumes responsibility for the checked results.

* A misplaced decimal point is also another example of a transcription error.

For example, writing 10.01 instead of 1.001

* Transcribed coding may also be a transcription error.

For instance, listing the hospital URL number for an elderly bypass patient to a neonate in intensive care.

* Atypical entries. This is where data is recorded that does not fit the normal pattern. It may indicate an out of control or dangerous situation but it may also be due to operator carelessness or inattention.

For example, look at the list of blood alcohol readings. Can you spot the atypical entry? What checks would you do to investigate this atypical entry further?

Driver 1 0.00 %

Driver 2 0.01%

Driver 3 0.07%

Driver 4 0.05%

Driver 5 9.99%

Driver 6 0.15%

There are a number of ways to ensure that entered data is correct and these include:

* checking the transcriptions a second time
* checking the transcriptions a second time working backwards from the bottom of a list to the top
* checking the sequence backwards and forwards where numbers are long and clumsy (e.g. 1042 1276 0098 6754)
* generating a graph containing the data, as transcription or other anomalous errors become more obvious when depicted in a graph (assuming an appropriate scale is used) rather than in a column of numbers
* having your supervisor or another person check that the data has been correctly transcribed from the original paperwork
* do any of these things after a break from the work
* setting up a sophisticated computer data entry/data checking program that checks data for appropriateness and flags suspect entries.

### Computer systems

There is a new trend towards storing data electronically in computer programs, by a simple spreadsheet or database, or more complex programs. A spreadsheet program is an electronic version of a table. A database is like an electronic version of a card index or filing cabinet.

Computer storage of data has several advantages over paper-based systems. Computer systems:

* allow fast access to data and printed reports that are neat and easy to read
* store large amounts of data and information in a small space
* quickly present the results in a variety of ways such as tables and graphs
* can be programmed to automatically check the data for some types of errors and to alert management of results that show poor quality control in production areas.

Another advantage of programs like spreadsheets or databases is that they can be programmed to perform calculations. This makes it easy to analyse the results mathematically and even to draw graphs based on the results. Reports can be printed out and sent to customers or regulatory bodies.

**Example:**

The key to correct data transcription is to use a system that reduces the number of manual transcriptions required and to always check the transcription for errors, preferably more than once or by more than one person.

|  |  |
| --- | --- |
| Practice activity icon | Activity 2.2 – Using workplace forms |

1. *Obtain copies of workplace forms that are used to transcribe data. Ask your trainer to show you how to transcribe data and answer the following questions.*
   1. *How is data transcribed?*
   2. *Who transcribes it?*
   3. *What are the common transcription errors associated with this work?*
   4. *How is the data transcription checked for errors?*
   5. *Who does this checking?*

## Rectify errors in data using enterprise procedures

When mistakes or errors are discovered, it is important that they are acknowledged openly rather than covered up. Every laboratory will make mistakes sooner or later. A process of systematic checking should discover the mistakes before they are passed onto a customer. Reports should be issued free from erasures if possible. You don’t need to advertise your mistakes to a customer if you pick them up and can correct them before the report is issued. Sometimes a mistake is only found after the customer has been supplied with the test results, often as a result of a customer querying or complaining about a result.

Mistakes and errors must be promptly dealt with. This may mean amending a calculation or repeating a test. In either case, the new data or result should be added to the record, and clearly linked to the original data that was found to be incorrect. The incorrect data should not be erased, but it must be made absolutely clear that it is no longer valid and a brief reason should be given for the change. The person making the correction must sign and date the correction. Neatly crossing out a faulty result, rather than hiding it with correcting fluid allows you to keep a record of the problems that occur with testing and data processing. There are several reasons for making corrections this way:

* It will be clear if someone tries to alter the record, at a later date, for dishonest purposes.
* The causes of the problems may be properly investigated in order to prevent the mistakes from being repeated.

If results have already been issued to a customer before a mistake was discovered, the customer must be promptly informed of the error and a new statement of results issued that clearly shows that it supersedes the report with the error.

Only by acknowledging errors and investigating them can we begin to understand the causes of problems. When you know what the causes of the problems are, you can put work procedures in place to ensure that, in future, the quality system works more effectively.

|  |  |
| --- | --- |
| Practice activity icon | Activity 2.3 – Data policy |

1. *Write down a summary of your company policy for dealing with:*
   1. *routine recording of normal test results*
   2. *typical errors in test results*
   3. *how errors are rectified*
   4. *who rectifies the errors?*

|  |  |
| --- | --- |
| Practice activity icon | Activity 2.4 – Record and check data |

1. *Describe how your enterprise (simulated laboratory) records and checks data. In your answer, be sure to include:*
   1. *the types of recording documents (screens if computer-based) and examples of how they are filled in*
   2. *examples of the common transcription and other errors associated with the recording of data*
   3. *the procedures used to rectify errors with an example of the rectification of an error.*

Topic 3

Calculate simple scientific quantities

# Calculate simple scientific quantities

## Introduction to some common data quantities

### Fractions

A fraction is a number that is not a whole number. It looks like this:

Where:

2 = the numerator

3 = the denominator

The denominator, 3, tells how many parts something is divided into and the numerator, 2, tells how many pieces you have.

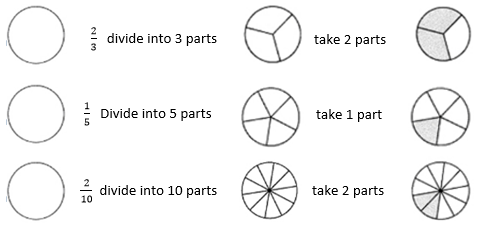


Figure 3.1 – Diagrammatic expression of fractions © TAFE NSW

The following examples are called equivalent fractions.

#### Reducing to the simplest form

Equivalent fractions can be found by multiplying or dividing the numerator and denominator by the same whole number. For example, in the fraction, both the numerator (2) and the denominator (8) are divisible by 2.

A fraction is in its simplest form when there is no whole number greater than one that can be divided into both the numerator and denominator.

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.1 – Simplest form |

*Reduce the following fractions to their simplest forms.*

### Decimals

A decimal, like a fraction, is not a whole number.

Decimals look like this 1.6, 0.17 and 2.16.

Most modern calculators will only give answers in the form of decimals. This means you will need to convert between fractions and decimals. There is usually an S⇔D button which will convert between decimal and fraction.

#### Converting between fractions and decimals

To change a fraction to a decimal you just need to divide the numerator by the denominator. You can easily do this division with your calculator.

Example:

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.2 – Decimal form |

1. *Convert the following fractions to decimal form;*

#### Decimal to fraction

To convert a decimal into a fraction, follow these steps:

**Step 1**

The decimal is the numerator of the fraction. The denominator is 1.

**Step 2**

Multiply the numerator and denominator by 10 until the numerator becomes a whole number.

**Step 3**

Reduce this fraction to its simplest form.

**Example:**

Convert 0.55 to a fraction.

Step 1

Step 2

Step 3

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.3 - Fraction |

1. *Convert the following decimals back to fractions;* 
   1. *0.35*
   2. *0.2*
   3. *0.125*
   4. *0.6*

### Ratio

**Example:**

A cleaning concentrate is used for mopping the wash up room floor.



Figure 3.2– Example of a cleaning product. © TAFE NSW

The directions for mixing the concentrate are one part concentrate to seven parts water.

A ratio compares the size of two quantities measured in the same units.

In the case of the cleaning concentrate, the ratio of concentrate to water used in mixing is written 1 : 7. This is read as ‘one to seven’.

Ratios give us the same information as fractions. In a quantity of made up cleaning solution, would be concentrate and would be water.

That is, for one cup of cleaning concentrate, we need to add seven cups of water making eight cups in total.

The order of the numbers is important. The ratio of water to concentrate would be 7 : 1.

The numerators of these fractions come directly from the ratio. The denominator is the total number of parts, which is always the sum of the parts. In this case.

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.4 – Forming ratios |

1. *Forming ratios*
   1. *Collect three recipes for mixtures used in your laboratory.*
   2. *Write down the ratios of the ingredients in the mixtures you have collected.*
   3. *Write down what fraction of the mixture each ingredient is (by weight or volume).*

#### Simplest form

When you calculate ratios you should always reduce the ratio to its simplest form.

**Example:**

The ratio 3:6 can be reduced to 1:2 by dividing both parts by 3.

A ratio is in its simplest form when there is no whole number that will divide into both its parts leaving whole numbers.

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.5 – Reducing the simplest form |

1. *Using the ratios you wrote in Activity 3.4, reduce each one to its simplest form.*

### Percentage

Percentage gives the same information as a ratio or fraction. Percentage tells the number of parts per hundred. The percent symbol % is written after a number that gives the number of parts per 100.

**Example:**

Fifty one percent (51%) of the population is female. This means there are 51 females in every 100 people in the population. Written as a fraction this would be . The percentage is the numerator, the denominator is always 100. As a decimal 51% is 0.51.

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.6 – Fractions to decimals |

1. *Rewrite each of the following percentages as a fraction and a decimal. Remember to reduce the fractions to their simplest form.*
   1. *25%*
   2. *83%*
   3. *120%*
   4. *0.5%*

#### Converting from fraction or decimal to percent

To convert a decimal to percent you multiply by 100.

**Example:**

Convert 0.5 to percentage. . Thus 0.5 is 50%.

To convert a fraction to percentage multiply by 100.

**Example:**

Convert to percent. . Thus, is 50%

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.7 – Fractions to decimals |

*Convert the following fractions and decimals to percentage.*

1. *0.125*
3. *0.75*

#### Finding a percentage of a quantity

To find a percentage of a quantity, use the formula;

Where;

A = the percentage of some amount

Q = the quantity

P = the percentage

**Example:**

Government employees have been awarded a 2.5% pay rise. You want to know how much extra pay you will receive each week. You currently earn $340 each week.

We know Q is the amount that is paid now: $340

We know P is the percentage pay rise: 2.5%

Therefore, we want to find 2.5% of $340

Substituting into

You will receive a pay rise of $8.50 per week.

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.8 – Percentage of a quantity |

1. *You need to increase the volume of a working solution by 20%. You currently prepare 12 litres.*
   1. *Calculate what will be the increase in volume?*
   2. *Calculate what will be the total volume?*

#### Percentage difference

Percentage difference can be calculated using the formula:

Where;

D = the percentage difference

S = the size of the quantity before the change

F = the size of the quantity after the change

**Example:**

You notice that in the process of autoclaving some media, its volume changes. The bottles contained 120 mL of media before autoclaving and had 112 mL after. The media recipe states that shrinkage will occur.

What percentage decrease has occurred?

Using the formula, we know;

S = 120 mL and

F = 112 mL

Substituting these into the formula:

The negative answer indicates a decrease. So the media decreased in volume by 6.7%.

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.9 – Percentage change |

1. *You notice in the lab store that the stocks of a particular chemical had reduced from 19.5 kg to 15.5 kg. Your supervisor had wanted the store to reduce its holding of this chemical by 25%. Has the percentage decrease been more or less than the supervisor wanted?*

## Statistical values of given data

This includes calculating the mean, median, mode and standard deviation

Statistics is concerned with the collection, presentation and interpretation of data, and predictions that can be made from the data.

Statistical methods are used widely in fields such as political polling, market research, production management, quality control, psychology and medicine.

After data has been collected, it can be presented in tables, diagrams, graphs and charts to provide more meaningful information and easy interpretation.

The following three diagrams show three different types of graphs/charts used to represent statistical information in a visual manner.

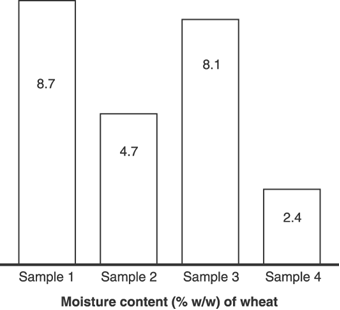


Figure 3.3 – Example of a bar chart. © TAFE NSW

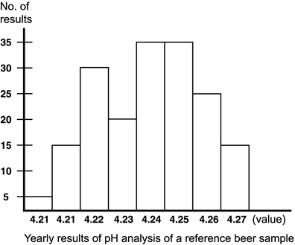


Figure 3.4 – Example of a histogram. © TAFE NSW

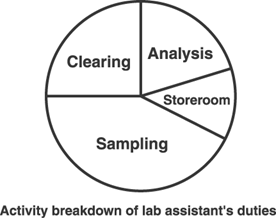


Figure 3.5 – Example of a pie chart. © TAFE NSW

### Measures of location

Often with a set of data, there is one value or item that is representative of the whole set. Three such measures are the mean, median and mode.

#### Mean

The mean ( ) is popularly known as the ‘average’. It is the most common measure used to obtain a measure of central tendency. Central tendency means a number or range of numbers that the data “cluster” around.

It is determined by adding all numbers in the data and then dividing by the number of items.

**Example 1:**

If test results for a group of students are:

9, 5, 7, 8, 8, 6, 10, 3

then,

The mean is easy to determine but has a disadvantage in that it is distorted (that is, moves away from where ‘most’ of the values are) if there are any extreme values different to the majority data.

For example, in the group of test results above, if one additional student obtained a score of 50, then the mean would become 11.7 and distort the mean average of the rest of the group.

When the data collected contains many items with a lot of repetition of certain values, it is useful to produce a frequency distribution table.

In the table, a tally is kept where a mark is made every time a value occurs. After completing the tally, the marks are added up to produce a frequency (the number of times that particular value occurs).

**Example 2:**

In a factory, a particular product is tested to determine the percentage of insoluble material remaining after it has been mixed with caustic soda.

The following results are obtained:

6, 7, 8, 6, 5, 6, 5, 7, 4, 9, 5, 6, 4, 5, 3, 6, 8, 8, 7, 9, 5, 6, 5, 5, 6

|  |  |  |
| --- | --- | --- |
| **% Insoluble** | **Tally** | **Frequency** |
| 0  1  2  3  4  5  6  7  8  9  10 | 1  11  ~~1111~~ 11  ~~1111~~ 11  111  111  11 | 0  0  0  1  2  7  7  3  3  2  0 |

Table 3.1: Frequency distribution table

Note that ~~1111~~ means 5 – it is much easier to obtain the frequency when all the marks in the tally are in bundles of 5.

This table shows us easily that most samples left 5% or 6% of insoluble material. The information could then be shown in a bar chart, histogram or pie chart to represent the data.

To obtain the mean for this information, instead of adding up individual values, we could obtain a total by multiplying each value by its frequency and then finding the total.

|  |  |  |  |
| --- | --- | --- | --- |
| **% Insoluble (x)** | **Tally** | **Frequency** | **% Insoluble × frequency** |
| 0  1  2  3  4  5  6  7  8  9  10 | 1  11  ~~1111~~ 11  ~~1111~~ 11  111  111  11 | 0  0  0  1  2  7  7  3  3  2  0 | 3  8  35  42  21  24  18 |
|  | Total = | 25 | 151 |

Table 3.2: Frequency distribution table

The mean was a good measure of central tendency in this case.

#### Median

The median (Me) is the middle value in an array, which means firstly all scores have to be put in order of smallest to largest.

Returning to the test results in Example 1:

9 5 7 8 8 6 10 3

When they are put in order,

3 5 6 7 8 8 9 10

↑

The middle of the list is between two (2) values, because there is an even number of data.

When this occurs, we obtain the mean of the 2 values that are in the middle.

For an odd number of data, it is easier to calculate the median such as in Example 2.

There are 25 in this sample, so when the data is put in order of smallest to largest (or in reverse order) the 13th value (6) would be the median. The median is a very good measure of central tendency and it is not distorted by extreme values – each value has equal effect on the median.

#### Mode

The mode (Mo) is the value that occurs most often in the data. There are problems with this because some data do not have one, or perhaps have more than one.

However, the mode is sometimes important because it represents the most ‘popular’ or most ‘common’.

**Example 3:**

Sizes of a particular T-shirt sold in a week are:

10, 10, 12, 14, 16, 16, 16, 18, 20

Size 16 occurs more than the others.

Mode = 16

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.10 – Statistical calculations |

1. *Obtain the mean, median and mode for the following heights (in cm) of students in a class.*

150, 147, 170, 139, 146, 147, 169, 175, 147, 139, 162, 153, 153, 162, 120, 133, 145, 160

Mean:

Mode:

Median:

1. *Obtain the mean, median and mode for the following data:*

3, 4, 4, 6, 5, 2, 4, 4, 4, 3, 9, 7, 8, 7, 5 , 6 , 6, 4, 4, 5

Mean:

Mode:

Median:

### Variation of data

Often we need to know how widely the data is scattered. This is called the spread or dispersion of the distribution. There are several ways of measuring spread. Two measures of spread commonly used are the range and standard deviation.

#### Range

The range is the difference between the highest and lowest values in the data.

For test results:

9, 5, 7, 8, 8, 6, 10, 3

This is easy to calculate but is affected by extreme values in the data – it does not give enough detail about the scatter of all the items from the mean.

#### Standard deviation

The standard deviation (s) measures the average deviation of individual values from the mean.

To determine this, we firstly calculate the difference between each value and the mean (the deviation) and then square this, obtaining the squared deviation. One reason for squaring the deviation is that we are only interested in how far each value is away from the mean, not whether it is larger or smaller than the mean.

There are two calculations of standard deviation, the sample standard deviation (s) and the population standard deviation (σ). In statistical terms, ‘s’ is really an estimate of ‘σ’. You should consult your workplace/laboratory supervisor if you are unsure of which measure you are to use. Here, we focus on the **sample standard deviation**.

The sample standard deviation is calculated by dividing the squared deviation by the number of items in the data less one (obtaining the ‘average’ squared deviation from the mean) and then obtaining the square root of this final value. This is an estimate of the population standard deviation (σ) which uses the same formula except it is divided by the number in the population (n) not n-1 as below.

Where;

*s* = standard deviation

x̅ = the mean

n = the number of items

2 = the total of all

For test results, 9, 5, 7, 8, 8, 6, 10, 3, it is then easiest to work in a table.

|  |  |  |
| --- | --- | --- |
| x |  |  |
| 9 | 2 | 4 |
| 5 | -2 | 4 |
| 7 | 0 | 0 |
| 8 | 1 | 1 |
| 8 | 1 | 1 |
| 6 | -1 | 1 |
| 10 | 3 | 9 |
| 3 | -4 | 16 |
|  |  | = 36 |

Standard deviation =

**Note 1:**

will always equal zero, a handy fact for checking that no mistake is made in the column.

**Note 2:**

An alternative standard deviation for populations uses n instead of n-1 and has the symbol ****. Most scientific calculators just have the symbols. To check that your calculator is doing the right thing, just calculate s for 21, 22, 23, and see whether you get 1.0 or 0.82.

The standard deviation is a measure of how much the values are spread out in the data.

Because it gives a measure of the extent to which results are spread around, standard deviation is a function that is used widely for controlling processes (‘process control’).

Imagine the manufacturing of reagents where a certain amount of salt is required to be delivered to each tube. Individual tubes are weighed over a period of time as they come off the manufacturing line – the mean (average) weight of salt is found to be 0.500 g with a standard deviation of 0.015 g.

The owner of the company sets the specification for the salt weight in any tube to be 0.500 g ± 0.045 g. Notice that 0.045 g is actually three standard deviations.

This is significant in statistics as it tells you that three standard deviations around the mean value represents 99.7 % of all tubes, provided the manufacturing process is operating correctly (that is, the process is said to be in ‘control’).

If, during routine sampling of the manufacturing process, a tube is found to have a weight of salt outside 0.500 ± 0.045 g it can be said that there is a high probability that the process is no longer in control. Some aspect of manufacturing (possibly the machinery) has changed to shift the average weight of the salt or to increase the standard deviation (spread). Such a result signals to the operator to take some action to bring the process back into control.

**Example:**

The use of mean +/- two or three standard deviations is used to set the upper and lower control limits on a process chart. In the example given above, the upper limit would be mean + 3 SD = 0.500 + 0.045 = 0.545 and the lower control limit would be mean – 3 SD = 0.500 – 0.045 = 0.455. The process would be in control when the weights of the tubes were in the range 0.455 g to 0.545 g. Process charts are looked at more closely in a later section.

## Calculate scientific quantities using given formulae and data

### The use of significant figures in measurements and uncertainties

Standard deviation is one component used for the calculation of measurement uncertainties. All the uncertainties pertaining to a measurement can be combined together to give the overall uncertainty but this is a complex area and will not be discussed further in this unit.

We know that all measurements are not exact. Often if calculations are performed it is tempting to quote answers to an excessive number of decimal places.

How many decimal places should an answer be quoted to? To answer this question we must learn a little bit about significant figures.

#### Which numbers are significant?

The number of significant figures is not the same as the number of decimal places. Below are some guidelines for determining the number of significant figures:

* All non-zero digits are significant:

For example, 356.4 has 4 significant figures.

* All zeros between significant digits are significant:

For example, 30.045 has 5 significant figures.

* All zeros to the right of a decimal point are significant:

For example, 2.00 has 3 significant figures.

* Zeros to the left in measurements less than one are not significant:

For example, 0.0024 has 2 significant figures.

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.11 – Significant figures |

1. *How many significant figures are there in the following?*

183 1024 0.04 15.301

91.00 56.9 207.8 0.56

#### Rule for adding and subtracting

Now that we know what a significant number is, we can look at how to quote answers to calculations. The rule depends on whether you are adding and subtracting or multiplying and dividing.

If you are adding or subtracting two or more measurements, the answer should be quoted to the same number of decimal places as the least precise measurement.

**Example:**

What is the combined mass of the following ingredients?

25.0 g 4.56 g 0.23 g 12.5 g?

The combined mass is:

25.0 + 4.56 + 0.23 + 12.5 = 42.29 g = 42.3 g

The least precise measurement is measured to one decimal place so the answer is quoted to one decimal place. Note that the measurements are added first and the final figure is rounded once the total has been obtained.

#### Rule for multiplying or dividing

If you are multiplying or dividing two (2) or more measurements, the answer should be quoted to the same number of significant figures as the least precise measurement.

**Example:**

Let’s suppose you measure (with a ruler) the thickness of a stack of 72 pieces of paper to be 2.1 cm. Your measurement has 2 significant figures. The thickness of one piece of paper is given by:

* thickness of paper = 0.029167 cm

Because the original measurement was only precise to two significant figures, your value for the thickness of one piece can only be quoted to two significant figures. You would write the answer as:

* thickness of piece of paper = 0.029 cm

You may find this a little tricky to begin with, so practise your skills on the following activities.

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.12 – Correct use of significant figures |

1. *Solve the following calculations and quote the answer to the appropriate number of significant figures:*
   1. *~1.356 m + 0.24 m*
   2. *~2.35 m x 1.2 m x 0.8 m*
2. *A laboratory technician works out the density of an ore sample. They measure the mass of the sample to be 34.1070 g on an electronic balance. They measure the volume of the sample to be 11 mL with a measuring cylinder. The density is then given by:*

*Round the answer to the correct number of significant figures.*

In reporting results of testing or analysis, you will often find that the procedure you are using states how many significant figures or decimal places to quote the result. For example, a pesticide analysis may tell you to record the pH of the sample to one (1) decimal place.

Notice for this example that even though you may be technically correct to quote to two (2) decimal places, all that is required for the purpose of the result is one (1) place. Avoid recording results that use unnecessary (or unwarranted) precision.

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.13 – Recording significant figures data |

1. *Look up the methods or procedures you routinely use and make a record of how many significant figures or decimal places are to be reported for each test. Do they look reasonable?*

### Scientific notation

Scientists often use **Standard Form** to write a number because it is then easy to express numbers that are very large or very small. **Scientific Notation** (or Standard Form) expresses any number as:

(a number between 1 and 9.999999...) x10power

Firstly, it is necessary to look at the meaning of negative powers of 10.

which means for example

The following table is helpful:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Number** | 100 | 10 | 1 | 0.1 | 0.01 | 0.001 |
| **10power** | 102 | 101 | 100 | 10-1 | 10-2 | 10-3 etc. |

To express any number in Standard Form, move the decimal point in the original number to ‘make’ a number between 1 and 9.99999 and continue as in the following examples.

**Example:**

* Express 456 000 in Standard Form.

* Express 0.003 456 in Standard Form.

Note that the power of 10 is always equal to the number of places the decimal point has moved: positive if the decimal point moves to the left, negative if it moves to the right.

Always look at your answer to see if it makes sense. For example, multiplying 4.56 by 104 would make a larger number, which is what we started out with. Likewise, multiplying 3.456 by 10-3 would make a smaller number, again as in the original.

* Express 5.980 x 105 as a decimal number.

(just move the decimal point 5 places to the right)

Notice that the number in Standard Form clearly shows that this number has 4 significant figures, so that the last zero does count!

* Express 3.456 x 10-4 as a decimal number.

(just move the decimal point 4 places to the left).

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.14 – Scientific notation |

1. *Express the following in Standard Form (Scientific Notation).*
   1. *430*
   2. *0.5*
   3. *0.000 469*
   4. *0.053 0*
   5. *866 300*
   6. *0.674*
2. *Express as decimal numbers.*
   1. *2.6 x 10-1*
   2. *8.95 x 10-5*
   3. *7.32 x 104*
   4. *4.3 x 100*
   5. *4.60 x 10-2*
   6. *1.34 x 105*

#### Square root

The square root of a number, shown by the symbol is a value when multiplied by itself gives the original number. For example;

* the square root of 4 (that is,) is 2 (that is, 2 x 2 = 4 )
* the square root of 28 (that is, ) is 5.3 (that is, 5.3 x 5.3 = 28)
* Note that the square root of 1 is 1 (that is, 1 x 1 = 1)

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.15 – Square roots |

1. *Where necessary use your calculator to find the square root of the following numbers (express your answer to two (2) decimal places):*
   1. *62*
   2. *3*
   3. *0.75*
2. *Check your answers by multiplying the square root by itself. This you produce the original number again. There may be slight differences due to the number of decimal points allowed on your calculator. Disregard these differences.*

## Calculating concentrations of solutions

### Calculating the mass of solute (compound)

Usually the workplace procedure for a test or preparation notes for making a solution will tell you exactly how much solute to weigh out to get the right concentration and volume of solution needed for the task. However, in some situations you will need to work out the required mass of a solute on your own to obtain a solution with a particular concentration. This is not too hard if you follow a few basic rules.

There are two measurements that you will have to make:

* amount of solute
* volume of solution so you can add the right amount of solvent

The amount of solute to be measured depends on the volume of solution that you want to make and the concentration that you require.

Concentrations can be specified in several ways.

#### Percent volume

This volume (% v/v) involves measuring the volume of a liquid solute and adding sufficient solvent to reach a particular final volume for the solution. It is calculated by using the following rule:

Where;

Volume of solute = what is being dissolved into the solution (mL or L)

Volume of solution = what the solute is dissolved into (mL or L)

Also, the same volume unit (either mL or L) is required for both the solute and the solution.

When you know the volume of solution and %v/v concentration required, the volume of solute to measure is given by:

**Example:**

The calculation for making 200 mL of 10% v/v alcohol solution is:

Therefore, to get 200 mL of 10% v/v alcohol solution, you must measure 20 mL of alcohol and make up the volume of the solution to 200 mL with pure water.

#### Percent weight

Volume (% w/v) involves measuring the weight (mass) of a solid or liquid solute and adding sufficient solvent to reach a particular final volume for the solution. The concentration is calculated by using the following rule:

Where;

* the mass unit for the solute is grams (g)
* the volume unit for the solution is millilitres (mL).

When you know the volume of solution and %w/v concentration required, the mass of solute to measure is given by:

The calculation for making 200 mL of 0.1% w/v peptone solution is:

So, to get 200 mL of 0.1% w/v peptone solution, you must measure 0.2 g of peptone and make up the volume of the solution to 200 mL with pure water.

#### Molarity

Molarity is an expression of concentration using moles of substance instead of mass, and is given by:

If the concentration is a molarity (M), the mass of solute is measured in grams and this is converted to moles prior to solving the formula, using the mass-moles relationship;

A mole is a measure of the number of particles of chemical. Each chemical will have a different molar mass. The terms molar mass and formula mass are often used to mean the same thing. The formula mass for a chemical is on the label of the bottle.

The volume is measured in litres (L) or millilitres (mL) but must be converted to litres for the calculation of the concentration by:

When you know the volume of solution and molarity concentration required, the mass of solute to measure is given by:

The calculation for making 200 mL of 0.1 M silver nitrate solution (formula mass on label of bottle = 169.9) is:

Therefore, to get 200 mL of 0.1 M silver nitrate solution, you must measure 3.398 g of silver nitrate and make up the volume of the solution to 200 mL with pure water.

Some standards will refer to the concentration of solutions in terms of normality (N). This is particularly common in American publications. Normality is a measure of concentration of the active ingredient based on its chemical formula. In cases where the chemical formula contains only one unit of the active ingredient, the normality is the same as the molarity of the solution.

**Example:**

The active ingredient in acids is the hydrogen ion. Hydrochloric acid has the chemical formula HCl which contains only one hydrogen, therefore one hydrogen ion.

For a solution in which 0.1 mole of HCl is dissolved in 1.0 L of solution:

* the molar concentration is 0.1 M
* the normal concentration is 0.1 N.

Sulfuric acid has the chemical formula H2SO4 which contains two hydrogens.

For a solution in which 0.1 mole of H2SO4 is dissolved in 1.0 L of solution:

* the molar concentration is 0.1 M
* the normal concentration is 0.2 N

If you are not sure about the units of concentration for a particular solution, check with your supervisor or the chemical supplier before you use the chemical.

Make sure that the volume units are compatible with the concentration units and remember that 1.0 L = 1000 mL. Use mL for percent (%) concentrations and use litres (L) for molarity (M) and normal (N) concentrations.

### Changing the volume of a solution

Usually the workplace procedure will tell you exactly how much of the chemical to weigh and the required volumes of liquids. Sometimes you will need to make up a smaller or larger amount of the solution, but you cannot just change the volume without changing the amount of solute or the concentration will no longer be correct.

The workplace procedure will give the amounts of solute needed to get a particular volume of solution at the right concentration.

**For example:**

* the procedure for preparing peptone solution is to use 1.0 g of peptone and 1.0 L of water
* This makes a litre of solution with 0.1% concentration.

Suppose you only require 200 mL (0.2 L) of this solution. You could make up one (1) litre anyway and only use 200 mL of it, or you could adjust the amounts of water and solute in the same way to make just 200 mL with the correct concentration.

If you only make up 200 mL of the solution, you would have to weigh less than 1.0 g of the peptone.

The rule for working out the required amount of solid is:

and make sure that the volume units are the same (both mL or both L) and remember that 1.0 L = 1000 mL.

### Parts per million

The concentrations of very dilute solutions may be expressed in parts per million (ppm).

In the same way that a 20% solution is 20 parts solute in one hundred parts solution, so a 20 ppm solution is 20 parts solute in one million parts solution.

Note that 1 mg of solute in 1 L of solution gives a concentration of 1 ppm.

Parts per million is the concentration unit often used to express the concentration of pesticide contamination in foods, and heavy metal contamination (for example, lead or mercury). It is more convenient to express a concentration of, say 5 ppm, than to express it as 0.0005% (w/v).

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.16 – Concentration calculations |

1. *What is the percentage concentration of a solution containing 18.4 g of NaCl made up to 800 mL with water?*
2. *What mass of Ca(OH)2 is required to make 1.5 L of a 4.0% (w/v) solution of Ca(OH)2 in water?*
3. *What is the concentration of solute (expressed as ppm) in a solution containing 0.007 g of solute in 1.5 L of solution?*

## Consistency with estimations and expectations

### Estimating to check calculations

When doing a calculation on paper or using a calculator, a very good habit to develop is to do an estimation to give you an approximate answer. If your calculation ‘agrees’ with your estimation, you then have the confidence that your answer is correct. You will know, for instance, that your calculated answer is not out by a factor of 10 which may have come about as the result of incorrectly keying values into your calculator.

Estimating can involve rounding the individual numbers in a calculation to the nearest 0.1, 1, 5, 10 or 100, as appropriate. In this way the calculation is very easy and often able to be done in your head.

For example: routine preparation of 11 L of reagent using 9.7 g of a compound. What if you need to make 6 L of the reagent instead? How much of the compound do you need? A quick estimation (‘ballpark figure’) for 6 L is about ½ of the usual volume and 9.7 g is approximately 10 g, therefore the estimate is around 5 g. The accurate calculation shows you should use 5.3 g and that the estimation of 5 shows that the calculation is most probably correct.

Because the calculation agreed with the estimated value you would have confidence that the answer was correct. Estimations are also useful for checking that the required materials are on hand.

For example, an estimation of the ethanol required to make 5.75 L of 45% ethanol would be:

.

A quick check of the solvent cupboard would tell you if you had 3 L as required.

**Example:**

Barry had just started working in a cattery and his first job was to order in the dry cat food for one month.

They had 107 cats in for agistment and the standard average diet for each cat was 250 g/day. A one month supply was required. He did the calculation on his calculator and promptly ordered in 8.025 tonnes.

His boss noticed the mistake when the 10 tonne truck arrived! The ball park figure was of course 750,000 g or 750 kg (100 X 250 X 30 g) and the correct calculation was 802.5 kg . ***Get into the habit of always estimating quantities and checking that your calculation is close to your estimate***.

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.17 – Estimating answers |

1. *Estimate the answer for each of the following calculations and compare your answer to the accurate answer from your calculator:*

   2. *3.25 hours running of an auto analyser that used 2.35 L of reagent per half hour*
   3. *175 L of a 35% w/v solution of reagent required what amount of undissolved reagent?*
   4. *A Jet aircraft uses 1250 L/hour of fuel and needs to fly for 8.25 hours. How much fuel is used?*

## Report all calculated quantities

**Terminology Caution!**

Never trust a dictionary for scientific terminology. The Pocket Oxford Dictionary describes the terms accurate and precision as follows:

* accurate — precise, exact, correct
* precision — accuracy, exactness.

Notice that they refer to each other and to ‘exact’ or ‘exactness’ and the terms appear interchangeable. In normal use, this is often the case. However, in laboratory science, their meanings are distinct as outlined in the next section.

In the world of measurement and laboratories **accuracy NEVER means precision** (see table below). When referring to general concepts and laboratory measurements, the strict definitions of accuracy and precision must be used.

Unfortunately for laboratory workers, both these terms have stricter names that are used in some laboratory areas but not in others.

All four terms are listed in the table below with an explanation of what each mean.

| **Term used in this unit** | **Meaning of the words** |
| --- | --- |
| **Accuracy** | **How close the measurement is to the true value.**  Note that all measurements have possible inaccuracies so we can never be completely sure we have the true value. This is why we need to estimate the **uncertainty of measurement** which quantifies how far our measurement could be away from the true value.  For example, 100 **± 2** g. |
| **Repeatability**  **(Precision)** | **This is a measure of the spread of values obtained when a sample or test item is measured a number of times.**  Note that it is one component used in the estimation of the uncertainty of measurement. |
| **Bias** | **This is a systematic error in our measurements. It biases our measurements away (offsets them) from the true value.**  Note that these errors occur consistently in our measurement system or when it is subject to certain environmental conditions. Many factors contribute to this bias and these are all components used in the estimation of the uncertainty of measurement. |

Table 2.1 - Term used in this unit

### Accuracy

The accuracy of a measurement is the closeness of the measured value to the true value. All measurements are subject to some possible inaccuracies as they are influenced by various thermal, electrical and mechanical phenomena. Organisations need to ensure that the measurements they carry out have an accuracy that is suitable for the tests they are undertaking. This means they are fit-for-purpose or that they meet any specification that they may be working to such as an Australian standard.

If the same thing is measured a number of times, then the measurements will often exhibit some scatter or spread of results. This is known as repeatability (or precision). For example, the following series of ten measurements range from 14.5 to 14.7 (a spread of 0.2):

14.6 14.5 14.6 14.6 14.5 14.7 14.7 14.6 14.6 14.6

On the other hand the following series of measurements vary from 3.3 to 72.4 (a spread of 69.1):

14.9 15.9 72.4 14.0 13.3 14.1 3.3 14.6 13.7 18.6

We would be reasonably confident in the average (the mean) of the first set of numbers. But we would not be very confident in the mean we would calculate from the second set of numbers because there is so much scatter or spread of results. It may indicate a problem in our measuring system or it may be a known limitation of the system.

Repeatability gives us an indication of how accurate our measurements are. However, accuracy is not just about getting repeatable results. There are factors that cause our measurements to be biased (or offset) from the true value. This bias is consistently there (often called systematic) but we are not normally aware of it.

Consider an archer who is aiming at the bullseye of a target. Suppose the first set of arrows is grouped closely together, but lie some distance from the bullseye as in the diagram below. We would say there was very good repeatability but a definite bias causing his arrows to consistently go high.

|  |  |
| --- | --- |
| fig 2-6 | **Good repeatability (precision) but a large bias which gives low accuracy.** |

The archer now adjusts the sight on the bow to remove this bias. The next set of arrows fall as on the diagram below. This is an example of a good repeatability (precision) with no bias.

|  |  |
| --- | --- |
| fig 2-7 | **High accuracy: Both good repeatability (precision) and no bias.** |

A second archer now has an attempt and produces the results shown in the diagram below. The arrows are not centred around the bullseye. The grouping of the arrows is also very poor, so there is a low repeatability (precision).

|  |  |
| --- | --- |
| fig 2-8 | **Low accuracy due to a combination of poor repeatability (low precision) and a large bias.** |

This second archer now adjusts the sight to increase the accuracy and produces the results shown below. This is an example of better accuracy and low precision.

|  |  |
| --- | --- |
| fig 2-9 | **Medium accuracy: Although there is no discernable bias the poor repeatability leads to the lack of accuracy for most arrows.** |

Just as the archer can adjust the sight on his bow, many laboratory instruments can be adjusted to minimise known biases (errors). However, instruments can usually only be adjusted at one or two points in their range. So, even after adjustment, instruments which are not perfectly linear may still exhibit some bias (error) in certain parts of their range. When an instrument is calibrated, the calibration report states the corrections that apply to different parts of its range. If the reported correction for a balance was 0.5 g at 200 g, the user would be able to add 0.5 g to the reading to correct for the bias (error) at that point.

Some reports may specify errors rather than corrections. Note that if the calibration laboratory determines that a balance is reading low by 0.5 g (a -0.5 g error) they would normally report a +0.5 g correction. A correction is what the user has to add to compensate for the error so it has the opposite sign.

Note that other biases (errors) can affect our measurements if we don’t use them properly. For example, instruments such as balances regularly need to have their zero checked otherwise another error is introduced.

Accuracy is a descriptive term. The measure of how inaccurate our measurements could be is the uncertainty of measurement. This is a complex area which includes an analysis of the repeatability of measurement and combines this with estimations of all the possible biases introduced by environmental and other factors that can affect our measurements. Estimation of the uncertainty of measurement is usually left to senior technicians, scientists or equipment and calibration experts to work out. In this unit you only need to be aware that uncertainties exist.

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.18 – Uncertainty of measurement |

1. *Choose one measurement task that you routinely perform in your laboratory.*
2. *List all the causes of uncertainty as you perform this measurement. To do this, think of all the aspects involved with the measurement including the manufacture of the measurement device.*
3. *How does each arise and how might uncertainties be controlled or lessened? Note: not all uncertainties can be controlled and they can never be entirely eliminated.*

### Why are units important?

Numbers are used frequently in everyday life and in the workplace. For these numbers to be meaningful, they must be accompanied by the correct unit.

For example, if you buy a length of wood from a hardware store, you give the assistant both a number and a unit. You may ask for two metres of shelving. In this case the unit is metres. If you were to leave out the unit and ask for ‘two of that’, the assistant would not know if you meant two metres or two yards or two feet and so on. In a laboratory, it is vital that a unit is included in every measurement you record.

### The SI unit system

You are probably aware that a given quantity can be measured in more than one unit. For example, some people may express their height in metres, others in feet and inches. This can sometimes lead to confusion. For example, you may be able to imagine how tall a 6 foot person appears, but not a person of 1.9 metres.

In particular, scientists found it confusing when other scientists from different countries or different workplaces used a different unit system. The metric system was first developed in France in 1790. It was not until 1960 that scientists agreed on a system of standard units that would be used around the world. This system is known as *Le Systeme International d’Unites*. It is usually referred to as the SI unit system. SI units were adopted as Australian legal units in 1960 and they are included in the National Measurement Act 1960. The Act is the legal basis for their use in Australia.

#### Base units

The SI unit system revolves around seven (7) base units. These are given in the table below.

|  |  |  |
| --- | --- | --- |
| **Quantity** | **Base Unit** | **Symbol** |
| length | metre | m |
| mass | kilogram | kg |
| time | second | s |
| temperature | kelvin | K |
| amount of substance | mole | mol |
| luminous intensity | candela | cd |
| electric current | ampere | A |

Table 2.3: SI base units

The first four units in the table are frequently used, so you should become familiar with them.

You should also be familiar with the rules for using units:

* Always leave a space between the value and its unit for example, 3.7 m not 3.7m.
* Use the unit symbol correctly (for example, m not M, g not gm).
* Do not express units in plural (for example, 13 m not 13 ms).
* A unit named after a scientist has an upper case symbol but the name of the unit is lower case (for example, kelvin, K).

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.19 – SI Base units |

1. *How many of these quantities do you measure in your laboratory? Put the SI unit for* *that quantity in the table below.*

|  |  |  |
| --- | --- | --- |
| **Quantity** | **Unit used in laboratory** | **Symbol** |
| **length** | **metre** | **m** |
| length |  |  |
| mass |  |  |
| time |  |  |
| temperature |  |  |
| amount of substance |  |  |
| luminous intensity |  |  |
| electric current |  |  |

#### Derived units

Sometimes base units are combined. For example, area is measured in units of (metres x metres) or m2. This type of unit is called a **derived unit**.

Some of these units are named after famous scientists. This makes the names of the units less complex. For example, in terms of base units, the unit for force would be ([kilograms x metres] / [seconds x seconds]). For simplicity, this unit is known as the **newton**.

Some common examples of derived SI units are given in the table below.

|  |  |  |
| --- | --- | --- |
| **Quantity** | **Derived SI unit** | **Symbol** |
| volume | cubic metre | m3 |
| pressure | pascal | Pa |
| energy | joule | J |
| force | newton | N |
| power | watt | W |
| density | kilogram per cubic metre | kg/m3 |
| area | square metre | m2 |
| velocity | metre per second | m/s |
| voltage | volt | V |
| electrical resistance | ohm | Ω |
| electrical conductance | siemens | S |
| electrical charge | coulomb | C |
| electrical capacitance | farad | F |
| frequency | hertz | Hz |
| inductance | henry | H |
| magnetic flux | weber | Wb |
| magnetic flux density | tesla | T |

Table 3.4 – SI units derived from SI Base units

### SI prefixes

After performing activities 2.22 and 2.23 you have probably found that you do not always use SI units in the workplace. This is sometimes because the SI unit is not of an appropriate size. For example, if you were dispensing small amounts of liquids, cubic metres would not be a convenient unit to use.

SI units can be made more convenient by the use of standard SI prefixes which indicate the multiples or submultiples of the unit. For example, a small length can be measured in units of millimetres (mm) – the prefix milli (measuring one thousandth) together with the standard unit (metre) now represents the smaller convenient unit of length, that is, 1 mm = one thousandth of a metre.

A list of commonly used standard SI prefixes is given in the table below. It is important to use prefixes correctly, for example, km not kΩ.

|  |  |  |
| --- | --- | --- |
| **Prefix** | **Symbol** | **Factor** |
| giga | G | 109 (one thousand million) 1 000 000 000 |
| mega | M | 106 (one million) 1 000 000 |
| kilo | k | 103 (one thousand) 1000 |
| milli | m | 10-3 (one thousandth) |
| micro | μ | 10-6 (one millionth) |
| nano | n | 10-9 (one thousand millionth) |

Table 2.5: Standard SI prefixes

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.20 - Prefixes |

*Do you use any of these prefixes in your workplace or everyday life? It may help you to look at your answers to the previous activities.*

1. *List the prefixes you use.*

### Converting SI units

There are two types of conversion we can make. These are:

* from the SI unit to the multiple/submultiple
* from the multiple/submultiple to the SI unit.

We will discuss each of these in turn.

Before we do this, it is worthwhile noting that Australian Standard AS1000 requires numbers to be expressed in the range 1-999; for example, 27 MPa not 27,000 kPa. Expressing numbers correctly therefore involves being able to convert between appropriate prefixes.

#### Multiples and submultiples

There are two steps involved in converting from the SI unit to the multiple/submultiple. These are given below.

**Step 1**

Use prefixes in Table 3 to find the conversion factor.

**Step 2**

Divide by the conversion factor.

These steps are illustrated in the following examples.

**Example**

A vacuum cleaner has a power rating of 1200 W. Express this power rating in kilowatts (kW).

**Step 1**

From Table 3 the conversion factor for kilo is 1000.

**Step 2**

To convert from W to kW we must divide by 1000.

**Example:**

A typical reaction time in operating a stopwatch is 0.2 seconds. Convert this to milliseconds (ms).

**Step 1**

From Table 3 the conversion factor for milli is

**Step 2**

To convert from s to ms we must divide by

Note: Dividing by 1/1000 is the same as multiplying by 1000.

The only way to become proficient at this process is to repeat it many times. Work through the following activity to practise the process before we move on to workplace related examples.

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.21 – Unit multiples and sub-multiples |

1. *Change the following measurements into the units shown. The prefix is indicated by underlined type.*
   1. *4 800 m to km*
   2. *6 456 000 W to MW*
   3. *1 560 000 Hz to GHz*
   4. *2 m to mm*
   5. *0.0003 V to mV*

#### Converting from multiples and submultiples

There are two steps involved in converting from the prefix to the SI unit. These are given below.

**Step 1**

Use prefixes in Table 3 to find the conversion factor.

**Step 2**

Multiply by the conversion factor.

These steps are illustrated in the following examples.

**Example:**

Green light has a wavelength of 540 nanometres (nm). Express this in metres.

**Step 1**

From Table 3 the conversion factor for nano is

**Step 2**

To convert from nm to m we must multiply by

**Example**

The resistance of the human body is about 1.5 mega ohm (MΩ).

Convert this to ohms (Ω).

**Step 1**

From Table 3 the conversion factor for mega is 1 000 000.

**Step 2**

To convert from MΩ to Ω we must multiply by 1 000 000.

(Note the answers 5.4 x 10-7 and 1.5 x 106 are written in scientific notation.)

Once again, the only way to become proficient at this process is to repeat it many times. Work through the following activity to practise the process before we move on to workplace-related examples.

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.22 – From prefix to SI base |

1. *Change the following measurements into the units shown. The prefix is indicated by underlined type.* 
   1. *25 ms to s*
   2. *47 MW to W*

*~50 mA to A*

* 1. *580 kJ to J*
  2. *650 nm to m*
  3. *3 GHz to Hz*

|  |  |
| --- | --- |
| Practice activity icon | Activity 3.23 – Workplace related examples |

1. *In preparing deionised water in a chemical laboratory, the method says ‘do not collect any water until the conductivity is less than 2 micro-siemens (µS)’. Express this value in siemens (S).*
2. *The pressure in an autoclave should be 100 kPa. Express this reading in Pa.*

## Conversion between different unit scales

Have a look at your answers to activities 3.22 and 3.23. You probably found that some of the units you use in the workplace are not SI units. For example, you measure volume in litres (L) or millilitres (mL) rather than m3.

Despite the introduction of the SI unit system, measurements are often made with a variety of different units. If you wish to compare the measurements taken in your laboratory with those:

* of another laboratory
* in a reference book
* in an instrument manual

You may have to convert from one unit scale to another. This can be done by following the procedure.

#### Converting between units

There are three steps involved in converting between different unit scales. These are given below.

**Step 1**

Find the conversion factor between the different unit scales.

**Step 2**

Decide whether to multiply or divide.

**Step 3**

Multiply or divide by the conversion factor.

Step 2 is the most difficult step, so we will look at it in more detail. To multiply or divide? That is the question. Suppose we wish to convert millilitres (mL) into m3. We will call ml the old unit and m3 the new unit. The conversion factor is:

We have one of the old unit, so we multiply to convert from mL to m3.

Suppose we now wish to convert from m3 to mL? The conversion factor is again given as:

We now have one of the new unit, so we divide to convert from m3 to ml.

This is best illustrated with examples.

**Example 1:**

Convert 50 mL to m3.

**Step 1**

The conversion factor is

**Step 2**

This is one of the old unit so we must multiply.

**Step 3**

**Example 2:**

Convert 0.02m3 to mL.

**Step 1**

The conversion factor is

**Step 2**

This is one of the new units so we must divide.

**Step 3**

Topic 4

Present data

# Present data

## Present data accurately

What do all the results sheets that you have looked at have in common? You probably found that the measurements were recorded in neatly arranged columns. Each column is headed with a title and a unit. We do the same thing if we are constructing a table of our own. This is best illustrated with an example.

Suppose we now ask the question: Does the reaction time depend on age? To answer this question several people of different ages measured their reaction times. We can record this information in the form of a table. In this example we have two quantities that vary:

* the age of the person
* the reaction time of the person

These are called variables (because they vary). We are trying to find out if the reaction time depends on age. We say then that reaction time is the dependent variable and age is the independent variable.

As we have two variables we will have two columns in our table. The independent variable is usually the first column of the table. Age is measured in units of years so the heading of the first column will be Age (years). Reaction time is measured in seconds, so the heading of the second column will be Reaction time (s).

The table would then be written:

|  |  |
| --- | --- |
| **Variation of reaction time with age** | |
| **Age (years)** | **Reaction time (s)** |
| 17 | 0.17 ± 0.005 |
| 25 | 0.19 ± 0.005 |
| 34 | 0.21 ± 0.005 |
| 45 | 0.22 ± 0.005 |
| 56 | 0.25 ± 0.005 |
| 70 | 0.34 ± 0.005 |

Table 4.1 – Data table. For completeness, the uncertainty in the measurement has also been noted.

Notice that the independent variable is arranged in increasing order. This makes it easier to spot trends in the measurements. It is also more convenient if the data is to be used for plotting graphs. Have you noticed a relationship between age and reaction time? We can say that reaction time increases with age. You will learn more about finding relationships between two variables in the graph plotting section of this section. Follow this checklist for recording measurements in the form of a table:

* each variable has its own column
* the independent variable is written in the first column
* the independent variable is written in increasing or decreasing order
* each column has a title and a unit
* the table has a title

The terms dependent and independent variable may be unfamiliar to you. Try not to let this confuse you. You can think of them as ‘the quantities that you measure’. Let us look at some examples of finding the dependent and independent variables.

|  |  |
| --- | --- |
| Practice activity icon | Activity 4.1 – Dependant and independent variables |

1. *Name the dependent and independent variables in the following examples.*
   1. *How does the mass of a kitten vary with its age?*

Dependent variable: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Independent variable: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

* 1. *How have the wages of laboratory assistants changed over the last few years?*

Dependent variable: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Independent variable: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

* 1. *Does the growth rate of a plant depend on the daily hours of sunlight?*

Dependent variable: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Independent variable: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

* 1. *Does the amount of gold in a quartz sample change with the specific gravity of the sample?*

Dependent variable: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Independent variable: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

|  |  |
| --- | --- |
| Practice activity icon | Activity 4.2 – Constructing a table |

*A company uses a process where sugar solution is fermented to produce certain compounds. Two different strains of yeast are being trialled to assess their fermentation performance. As part of this assessment the specific gravity of the solution from each fermentation is periodically tested. The following results were obtained:*

***Specific Gravity***

*Time(Days), Yeast 1 Fermentation, Yeast 2 Fermentation*

*2.0, 18.2, 15.4*

*2.5, 14.6, 13.2*

*3.0, 11.4, 11.8*

*3.5, 8.6, 9.8*

*4.0, 5.0, 7.0*

*4.5, 2.2, 6.0*

1. *Construct an appropriate table and enter the above measurements into it.*

|  |  |
| --- | --- |
| Practice activity icon | Activity 4.3 – Recording data in a table |

1. *You are going to measure how the temperature of a cup of boiling water changes with time.*
   1. *Decide which variables are;*
      1. *Dependent:*
      2. *Independent:*
   2. *Read through the whole procedure below, then construct a suitable table below in the space provided in which to enter your data.*

**Procedure:**

1. Boil a kettle and fill a cup with boiling water.
2. Record the temperature of the water at one minute intervals for ten minutes.
3. Enter your measurements into your table.

### Using graphs in the workplace

A graph is a way of representing information as a picture.

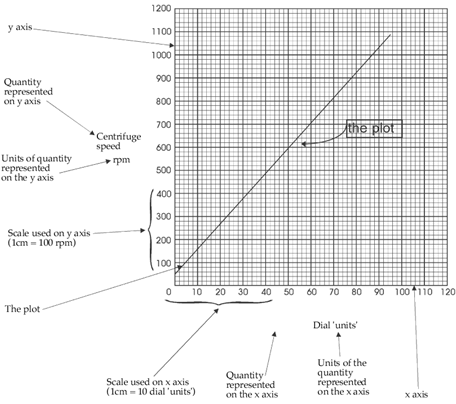
The parts of a graph are:

Figure 4.1- Graph of centrifuge speed by dial setting with explanatory text

|  |  |
| --- | --- |
| Practice activity icon | Activity 4.4 – Identifying the parts of a graph |

1. *Find three graphs from work, online, in newspapers and other publications. Identify the following parts of the graphs you have found:*
   1. *title*
   2. *quantity represented on the x-axis*
   3. *the units of the quantity of the x-axis*
   4. *the scale used on the x-axis*
   5. *quantity represented on the y-axis*
   6. *the units of the quantity of the y-axis*
   7. *the scale used on the y-axis.*
2. *Describe the shape of the plot. Is it a straight line, is it a curve or is it some other shape?*

## Reading graphs

You can find information by reading graphs.

**Example:**

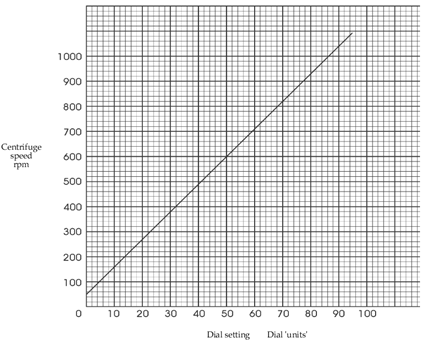
The following graph can be used to set the required speed of the laboratory centrifuge

Figure 4.2 Centrifuge speed by dial setting without explanatory text

If the dial setting is 45, can you read the graph to find out how fast the centrifuge is spinning?

The steps in reading a graph are:

* check if the quantity you know is represented by the x-axis or the y-axis

|  |  |
| --- | --- |
| **If it is on the x-axis then:** | **If it is on the y-axis then:** |
| * locate the value of the quantity you know on the x axis | * locate the value of the quantity you know on the y axis |
| * travel vertically from the axis to the plot | * travel horizontally from the axis to the plot |
| * now travel horizontally from the plot to the y-axis | * now travel vertically from the plot to the x-axis |
| * read the value of the scale of point you get to on the y-axis | * read the value of the scale of the point you get to on the x-axis |
| * this is the reading. | * this is the reading. |

You know the centrifuge setting is 45. This is represented on the x-axis.

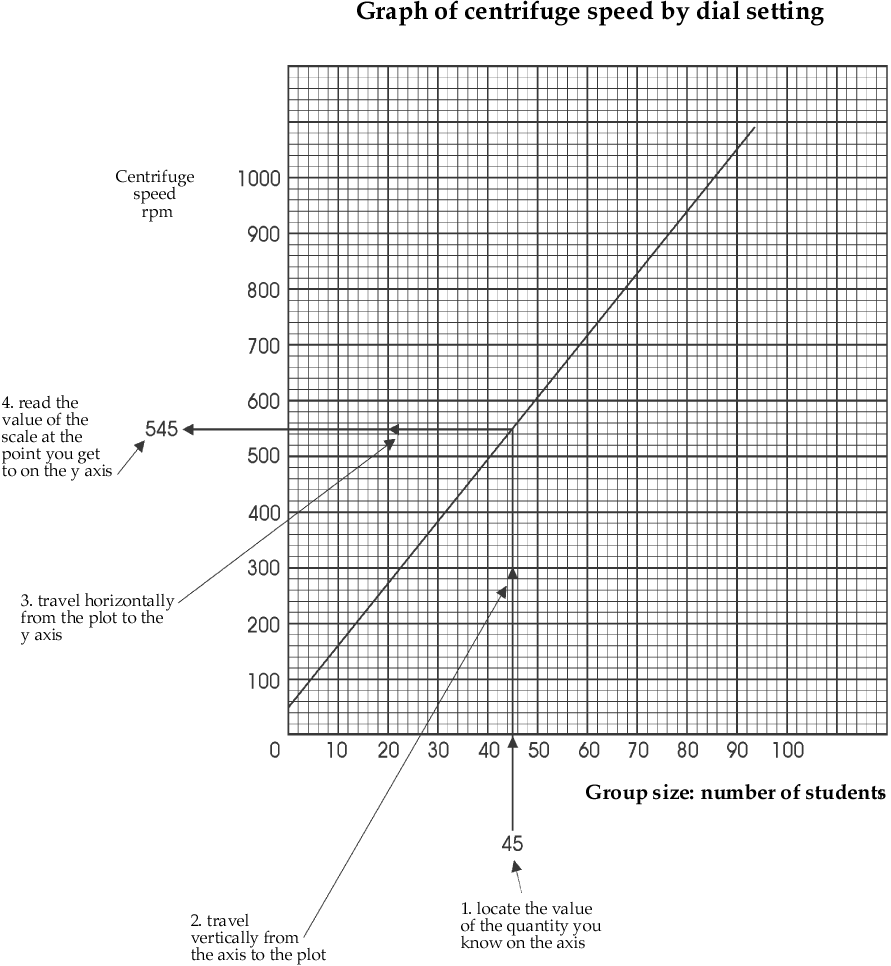
Following the other steps:

Figure 4.3 – Graph of centrifuge speed by dial setting showing how it is used to determine an answer. © TAFE NSW

You determine that the speed of the centrifuges is 545 rpm.

|  |  |
| --- | --- |
| Practice activity icon | Activity 4.5 – Reading graphs |

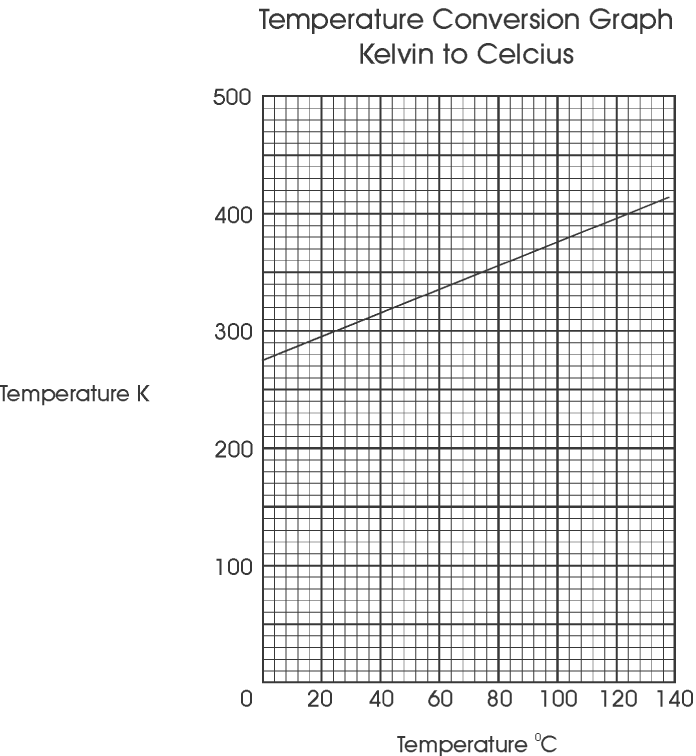
1. *******Read the values indicated on the following graphs.*

Figure 4.4 - Temperature conversion graph kelvin to degrees Celsius. © TAFE NSW

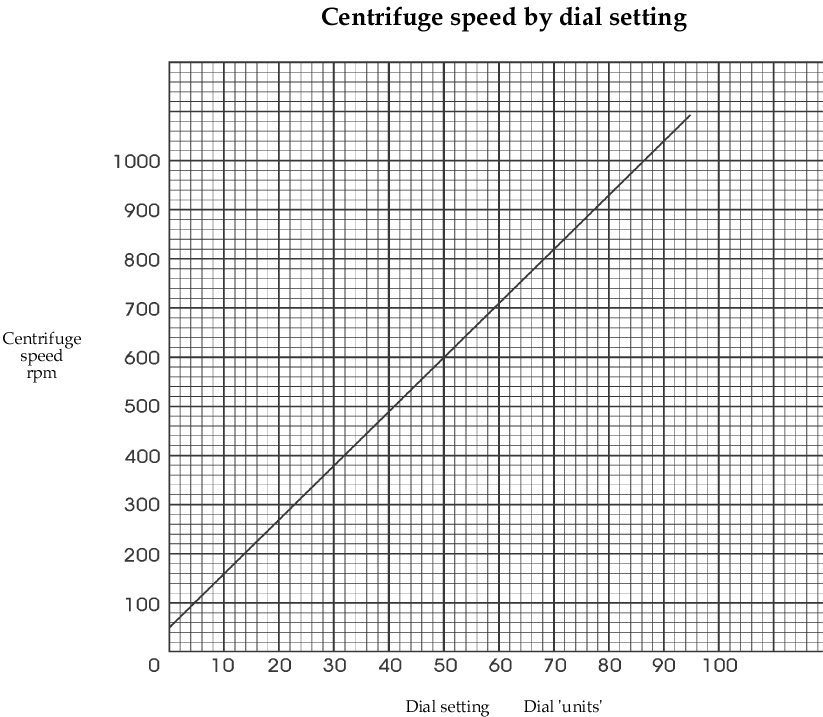
* 1. *What is the temperature in kelvin when it is 20 °C?*
  2. *****What is the temperature in degree Celsius when it is 350 K?*

Figure 4.5 - Centrifuge speed by dial setting. © TAFE NSW

1. *Find the centrifuge speed when the dial setting is 70.*
   1. *What will be the dial setting if a speed of 226 rpm is required?*

## 

## Graph plotting

Trying to find the relationship between two variables (or quantities) is often difficult to do from a column of numbers. Trends or relationships between two quantities (variables) can be seen much more easily if the data is plotted on a graph. In other words, a graph provides a visual representation of the data.

In this section we will cover how to plot and interpret a line graph. We will begin by describing each step of the process in detail. Then we will give a list of step-by-step instructions for graph plotting.

### Choice of axes

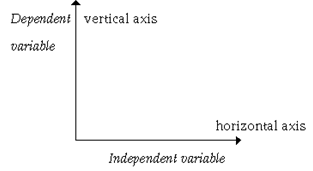
In a graph, the two variables are plotted on a set of axes as shown in the diagram below. The independent variable is usually plotted on the horizontal axis. The dependent variable is usually plotted on the vertical axis.

Figure 4.6 – An explanation of graph axes. © TAFE NSW

This makes the graphs much easier to interpret. For example, consider Activity 3.3. The aim was to see how the temperature of a cup of hot water changed with time. In this case, temperature is the dependent variable and time is the independent variable. Some typical results are shown in the graph below.

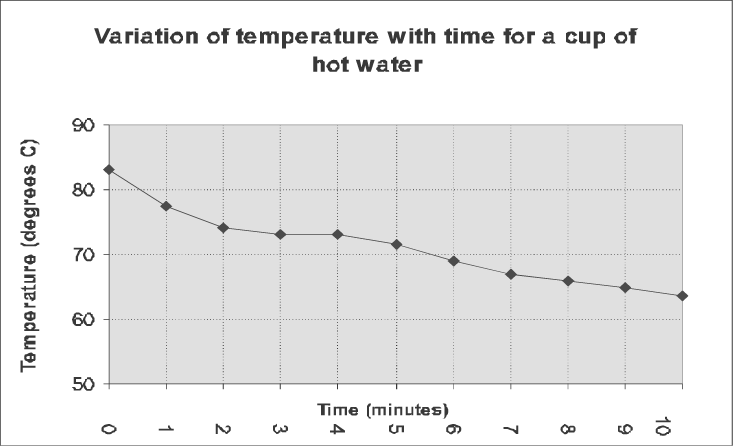


Figure 4.7 – An example of a proper graph. © TAFE NSW

From this graph we can see clearly that the temperature gradually decreases with time. Suppose we plotted the results the other way around, i.e. with the independent variable, time, on the vertical axis. The graph would now look like the one below:

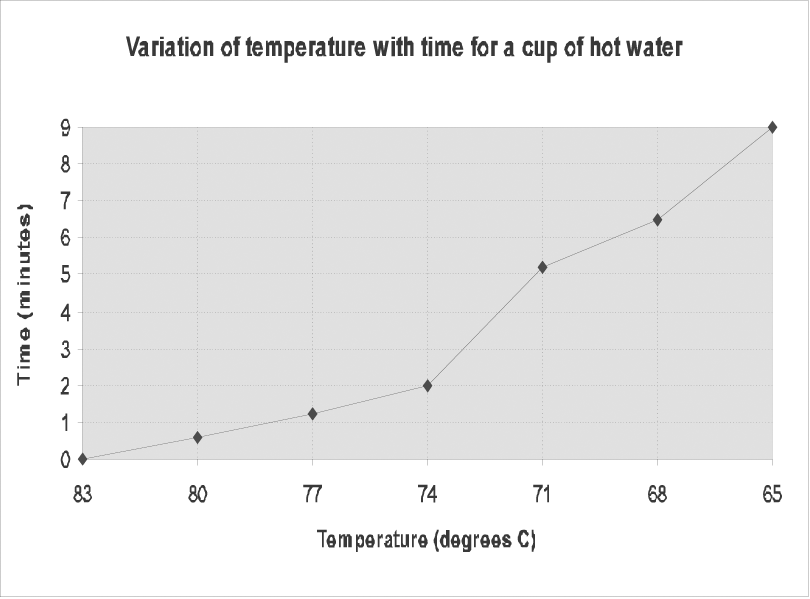


Figure 4.8 – Example of a not-so-great graph. © TAFE NSW

Notice how difficult it is to see the variation of temperature with time from this graph. You end up twisting your head in all sorts of peculiar directions! This is why the independent variable is plotted on the horizontal axis.

### Working out the scale

Choose a scale that fills as much space as possible. For ease of plotting make sure that each square represents an order of 1, 2 or 5  for example, 20, 100, 0.5. To do this:

**Step 1**

Decide how much space a graph is to use.

**Step 2**

Look at the range of values to be marked on the axis.

**Step 3**

Divide the range of values to be shown by the space available.

**Step 4**

Round up to the nearest order of 1, 2, or 5.

Let us illustrate this with an example. The data for the graphs showing the temperature variation with time for a cup of hot water is given in the following table. From this data we will construct a graph as shown.

|  |  |
| --- | --- |
| **Time (minutes)** | **Temperature (°C)** |
| 0 | 83 ± 0.5 |
| 1 | 78 ± 0.5 |
| 2 | 74 ± 0.5 |
| 3 | 73 ± 0.5 |
| 4 | 73 ± 0.5 |
| 5 | 72 ± 0.5 |
| 6 | 69 ± 0.5 |
| 7 | 67 ± 0.5 |
| 8 | 66 ± 0.5 |
| 9 | 65 ± 0.5 |
| 10 | 64 ± 0.5 |

Table 4.2 - Variation of temperature with time

Notice that we have once more included an uncertainty for completeness. We will not worry about how to include the uncertainty on a graph. Ask your trainer/supervisor about this if you are interested.

Let us follow the three steps above for the horizontal axis:

**Step 1**

Decide how much space a graph is to use. Let us suppose 15 cm.

**Step 2**

Look at the range of values to be marked on the axis.

Time is the independent variable, and the values range from 0 to 10 minutes. The range is then 10 minutes.

**Step 3**

Divide the range of values to be shown by the space available.

* space available = 15 cm
* range = 10 minutes

Therefore each cm can represent (10/15) or 0.67.

**Step 4**

Round up to the nearest order of 1, 2, or 5.

* 0.67 can be rounded to 1.

On the graph, each centimetre will correspond to one minute. This is shown in the graph as follows. Let us repeat this process for the vertical axis:

**Step 1**

Let us suppose we have 10 cm.

**Step 2**

Temperature is the dependent variable. The values range from 64 to 83 °C. The range is then 19 °C.

**Step 3**

* Space available = 10 cm
* range = 19 °C

Therefore each cm can represent (19/10) or 1.9 °C.

**Step 4**

1.9 can be rounded to 2.

On the graph, each cm will correspond to 2 °C. This is shown on the following page. Note that the scale on the axes does not have to begin at zero.

### Plotting the points

Once the axes have been drawn and labelled, the points are plotted. Let us consider the second point as an example. This point represents a temperature of 77.5 °C at a time of one minute.

**Step 1**

Find the 1 minute mark and the mark representing 77.5 °C.

**Step 2**

Imagine a line running vertically upwards from the 1 minute mark and another running horizontally across from the 77.5 °C mark.

**Step 3**

Mark the point where the two imaginary lines meet with a small cross or a dot.

Repeat this process for all the other data points. If the points form a straight line, draw a straight line through the points with a ruler. Otherwise, draw a smooth curve through the points.

#### Summary

Step-by-step instructions for plotting a graph

**Step 1**

Determine the dependent and independent variables.

**Step 2**

Draw a set of axes labelled with the independent variable on the horizontal axis and the dependent variable on the vertical axis. Make sure the graph is fairly large.

**Step 3**

Work out a suitable scale for each axis. Ensure that each square represents an order of 1, 2 or 5.

**Step 4**

Write numbers representing the scale on each axis, marking the axis with a neat ‘dash –‘.

**Step 5**

Label each axis with a quantity and a unit.

**Step 6**

Plot the points.

**Step 7**

Join the points with a straight line or a smooth curve.

**Step 8**

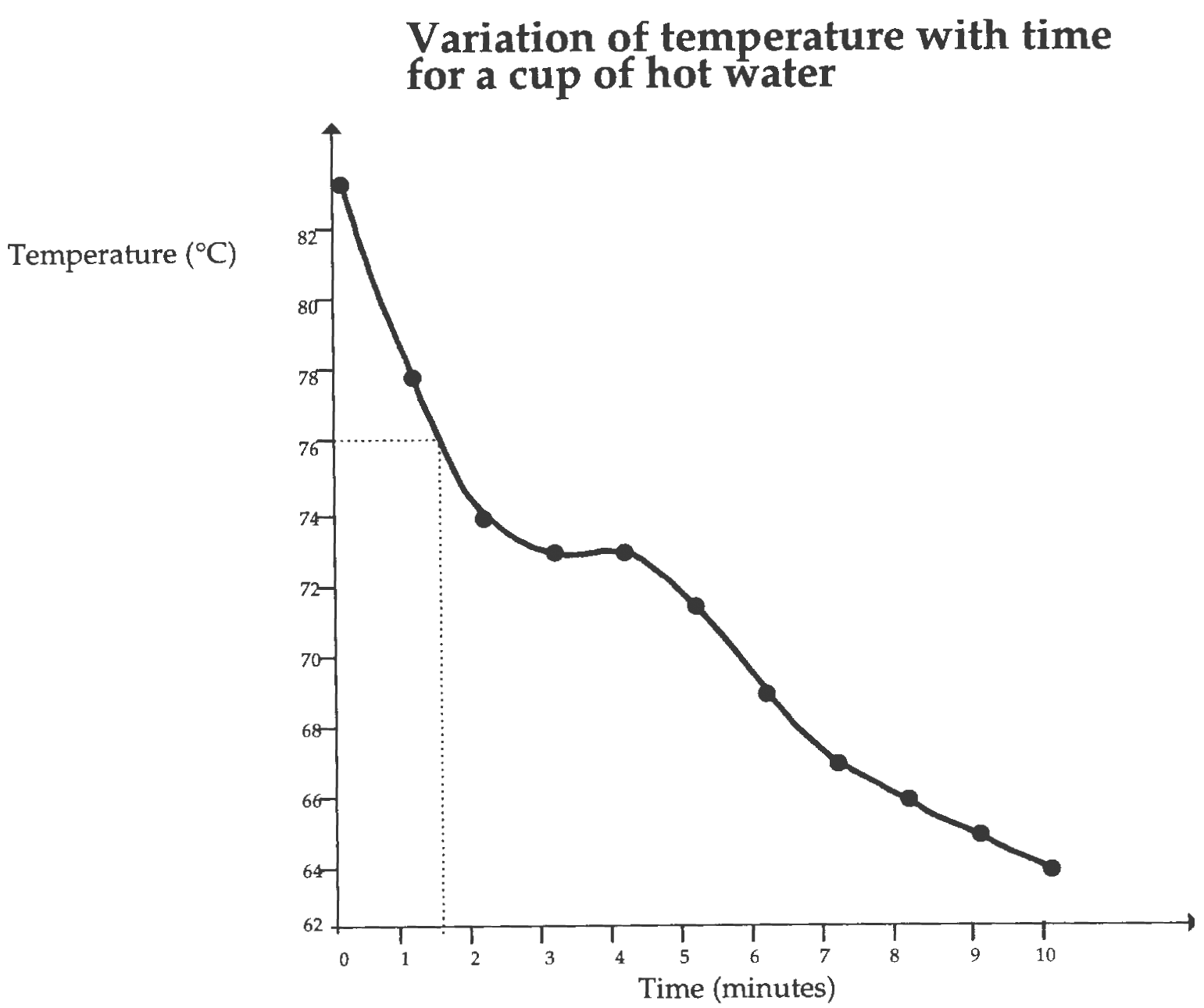
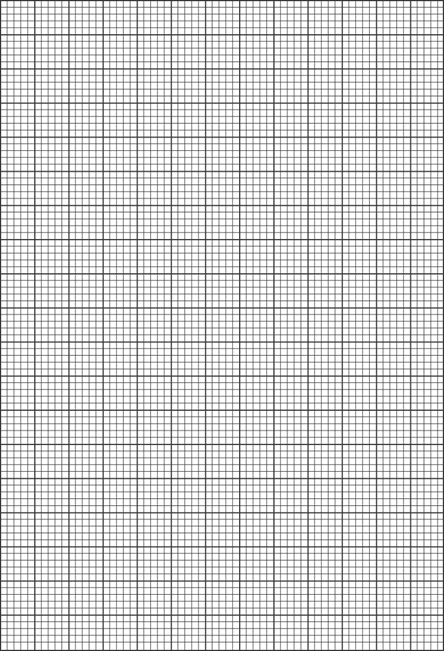
Label the graph with a title. The final graph is shown below.

Figure 4.9 – Variation of temperature over time for a cup of hot water. © TAFE NSW

|  |  |
| --- | --- |
| Practice activity icon | Activity 4.6 – Graph plotting |

1. *Plot a fully labelled graph of reaction time versus age using the data in the table at the start of this section.*

## Reading and interpreting line graphs

### Reading from a graph

We can use a graph to obtain meaningful information. For example, suppose we wish to know at what time the temperature of the water was 76 °C. We would draw an imaginary horizontal line from the 76 °C mark until it reached the line of the graph. We would then draw an imaginary vertical line down to the horizontal axis. The point where this vertical line crosses this axis gives the time that the temperature of the water was 76 °C. From the figure 3.7 it can be seen that this is 1.7 minutes. This process is called interpolation.

### Finding the relationship between two quantities

The relationship between two quantities can be determined by examining the shape of the curve of a line graph. If advanced graphing techniques are used, the exact relationship can be found. In this module we will be looking only at general trends. Some of these are indicated in the graphs below.

|  |  |  |
| --- | --- | --- |
| Temperature is proportional to time.  This is an exact relationship called a linear relationship. | | **fig 3-6a** |
| Temperature increases rapidly with time. | | **fig 3-6b** |
| Temperature decreases rapidly with time. | | **fig 3-6c** |
| Temperature gradually decreases with time. | | **fig 3-6d** |
| Temperature gradually increases with time. | | **fig 3-6e** |
| Temperature is constant with time. | | **fig 3-6f** |
| Practice activity icon | Activity 4.7 – More graph plotting | |

1. *Use your data table from Activity 4.6 to plot the variation of specific gravity with time for the two fermentations. You can plot both curves on the same set of axes.*
2. *How long did it take for Yeast 1 and Yeast 2 fermentations to reach 8.0 Brix (measure to the nearest 0.1 days)?*
3. *After how many days did Yeast 1 and Yeast 2 fermentations have the same specific gravity (measure to the nearest 0.1 days)?*
4. *What is the relationship between specific gravity and time for each fermentation?*

## Histograms and bar graphs

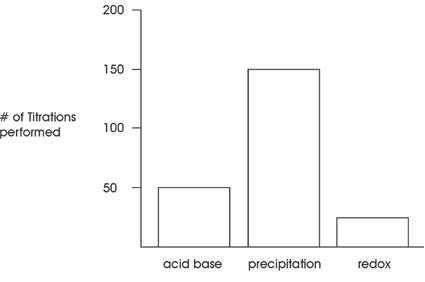
Histograms and bar graphs are another pictorial way of representing information.

Figure 4.10 – Titration test frequency for December to January. © TAFE NSW

The bar graph above shows the number of times a particular event happens in distinct categories. For example, it is the number of times a test is carried out. Each test type would be a category.

Histograms show the number of times in a particular range an event happens. For example, the Histogram below shows bacteria counts on an agar plate. The bacteria count ranges are: 0–49, 50–99, 100–149, etc.

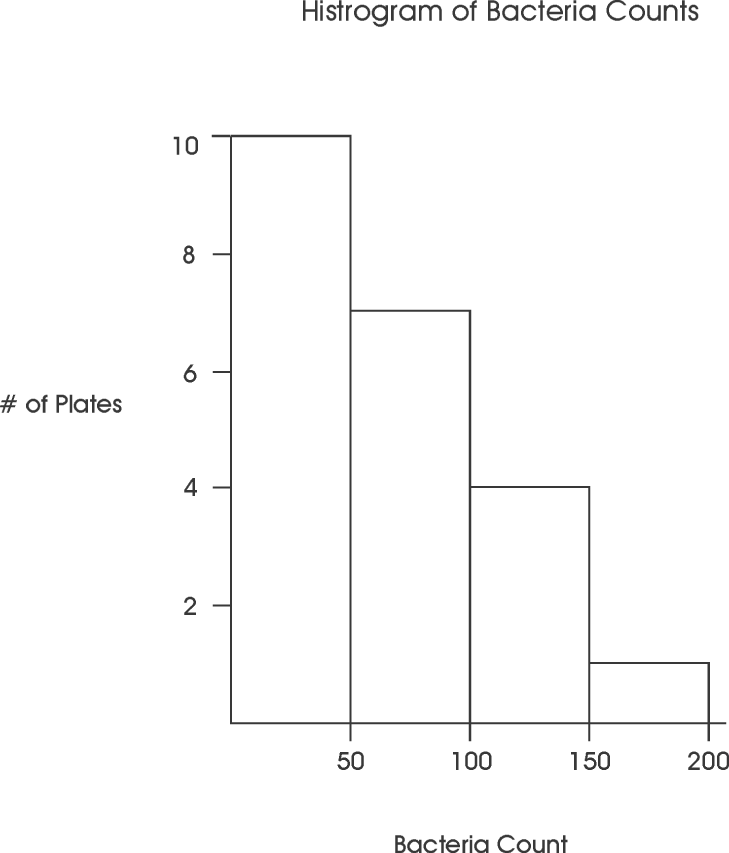


Figure 4.11 – Bacteria count. © TAFE NSW

### Reading a histogram or bar graph

Look at Figure 3.8. To find out the number of precipitation titrations performed in this lab, you would:

* locate the bar representing precipitation titrations
* read the value from the y axis which corresponds to the height of the precipitation bar.

One hundred and fifty precipitation titrations were carried out in the three month period, December to January, in the lab. Histograms and bar graphs are read in the same way.

|  |  |
| --- | --- |
| Practice activity icon | Activity 4.8 – Reading histograms and bar charts |

1. *How many plates had a bacteria count of between 100 and 149 in Figure 3.9 above?*

### Constructing a histogram or a bar graph

**Example:**

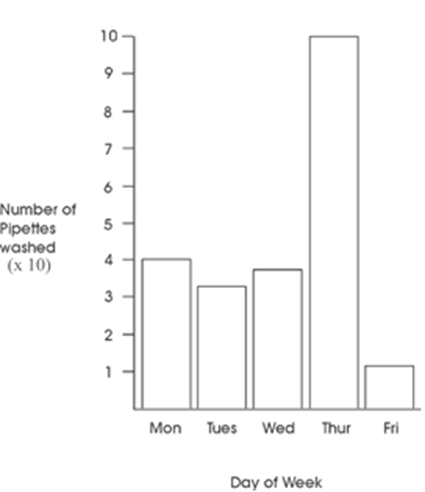
You have been recording the number of pipettes that are washed each day.

You want to represent this information on a Bar Graph.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Day** | **Monday** | **Tuesday** | **Wednesday** | **Thursday** | **Friday** |
| Number of pipettes washed | 40 | 32 | 37 | 98 | 12 |

First, there are five categories. Each day of the week is a category. Each category will have a bar. The width of each bar should be the same. The space between each bar will also be the same. You decide to have bars 2 cm wide and a space of 0.5 cm between each bar.

Next, decide on a scale for the y axis. The highest bar will be Thursday which will need to be 98 high (just less than 100). Use 2 cm for every 10 pipettes. The Thursday bar will be just less than 20 cm so this will fit well on a page.

Figure 4.12 – Bar graph of pipettes washed per day. © TAFE NSW

Histograms are drawn in the same way, except no space is left between the bars. The size of the range of each bar should also be the same.

|  |  |
| --- | --- |
| Practice activity icon | Activity 4.9 – Drawing a histogram and bar chart |

1. *The number of test tubes washed during the week was also recorded. Draw a Bar Graph of this information.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Day** | **Monday** | **Tuesday** | **Wednesday** | **Thursday** | **Friday** |
| Number of test tubes washed | 60 | 72 | 72 | 89 | 101 |

## Features and trends in the data

In the table of reaction time versus age it was obvious that as age increased so did reaction time. This is an obvious trend in the data. One common way of presenting data in the laboratory or manufacturing context is the use of a Process Chart. This chart allows the easy visualisation of trends, shifts and other features in the data and is often linked with QC processes.

### Process charts

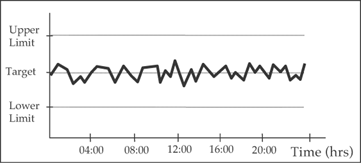
The normal situation is for a random arrangement of points on either side of the target. There should be no points outside of the upper or lower target limits – the process or product is said to be within specification. This process is stable with all values near the target.

Figure 4.13 – A plot of data where the data is stable around the target value. © TAFE NSW

When a value does appear outside of the target limits (either above the upper or below the lower limits) you should investigate. This variation is probably a ‘special cause’ because this is not normal for the system.

Here are some examples of process and what they may tell you:

This process starts with a normal variation pattern, then with a point above the upper limit. This is not normal for the system. There is probably a special cause such as broken or poorly adjusted equipment. Prompt action has fixed the problem and the system has been brought back within target again (run after the high point is now within acceptable limits again).

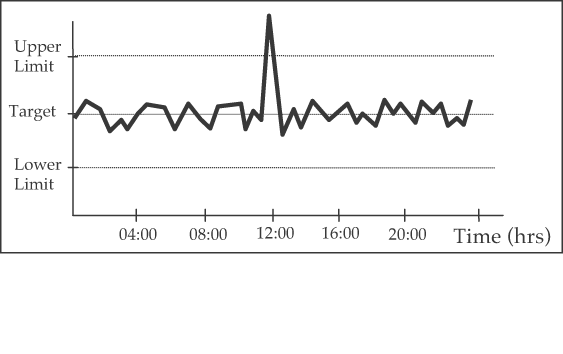
****

Figure 4.14 – This data displays normal process with an interruption due to unknown reasons. © TAFE NSW

The pattern below is called a run. It appears that there has been a permanent or sustained change in the process.

The average of this process may have changed due to a new procedure. If the change is beneficial, the next chart should have the new average on it.

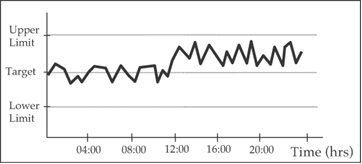
If the change is not deliberate, it should be investigated, particularly if it makes it harder to meet product specifications.

Figure 4.15– Example of when a process changes. Constant values change but continue as constant.

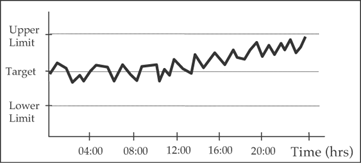
The next example shows a trend that is approaching the upper limit. This represents a gradual change, such as equipment that is wearing out. It should be investigated and corrected before it goes too far, or you will start to get out of specifications with your product.

Figure 4.16 – Example of a change over time. This process is wandering off course. © TAFE NSW

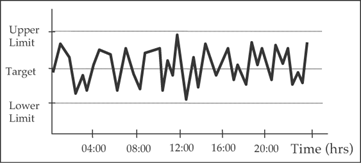
This figure appears “all over the place!” Here most of the results are spread out away from the target. This process has a lot of variation and is probably caused by making too many adjustments.

Figure 4.17 – Example of a stable process with high variation. © TAFE NSW

In this final case, the results were all very close to target. If this was normal then the UCL and LCL should also be close to the average. If results suddenly change to being close to the centre, there is probably something wrong with the collection/processing of data.

### Example of a very stable process

Figure 4.18 – Example of a very stable process. © TAFE NSW

### Recognising variations

If you collect data over a period of time you will be able to see what the values usually are when the process is working normally, so you can recognise when it is malfunctioning. If the results are within the normally accepted limits, it is highly probable that they are correct. If they are outside of the normal limits, you should report the result to your supervisor and investigate the cause. It may be that the result is correctly showing an alteration of the process. It may also be that the process is normal, but there is an error that has been made in testing or recording of the result.

**Example:**

A special set of rules are sometimes used to determine whether a process is out-of-control or not. They are called the Westgard Rules and can appear complex, but are really relatively straight forward. They can also be keyed into automated processes to ‘flag’ when an abnormal situation is arising or has arisen. If the Westgard Rules are used in your laboratory, then you need to understand them.

|  |  |
| --- | --- |
| Practice activity icon | Activity 4.10 – Trends in data |

1. *Find some process charts from your workplace (ask for charts that show interesting features). Identify the parts of the charts you have found:*
   1. *title*
   2. *quantity represented on the x-axis*
   3. *the units of the quantity of the x-axis*
   4. *upper control limit and explain how it was determined*
   5. *lower control limit and explain how it was determined*
   6. *explain any trends or features in the data*

Topic 5

Store and retrieve data

# Store and retrieve data

Now that we have a better understanding of what a laboratory is and does, as well as understanding the values (that is, numbers and units) associated with laboratory analysis, we can discuss the flow of data that will accompany the work done to get it.

## Data sources

The first question we can ask is *where can* **data** *come from*?

This question is best answered by exploring what a laboratory does from beginning to end. Generally speaking (as each lab is different), the workflow in a lab will consist of the following stages:

* Customer enquiry
* **Sample receipt**
* Sample pre-treatment
* Sample testing and analysis
* **Calculations**/determinations
* **Quality checks**
* Reporting of results

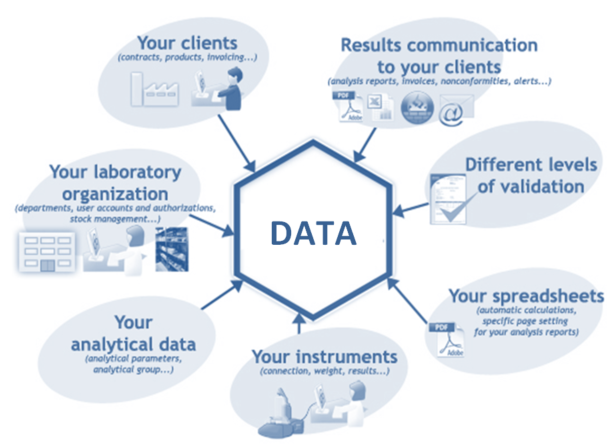


Figure 5.1 – Example of a generalised laboratory data workflow. © DAMA UK 2013

|  |  |
| --- | --- |
| Practice activity icon | Activity 5.1 – Types of data |

1. *What type of data could be generated from each stage of data workflow in your workplace or college? Once the data is collected, how could that data be processed? Two examples have been provided for clarity. Complete the remaining rows.*

| For this type of work… | What type of data is it? | How could the data be processed? |
| --- | --- | --- |
| Customer service | Names, locations, addresses, type of work | Analysed for sales trends |
| Sample receipt |  |  |
| Sample preparation |  |  |
| Analysis |  |  |
| Calculation processes |  |  |
| Statistical treatment |  |  |
| Quality | Compliance data | Compared to other ‘benchmark’ data |

## Storing data

The previous section explored the sources of data. Once data has been generated, the data needs to be stored appropriately. The ‘path’ data takes depends on how it was collected in the first place – physically or electronically.

If the data is generated electronically, then it is likely that the data will be stored electronically. If the data was physically recorded (that is, written on paper for example), then the physical paper will need to be stored in an equally physical location. Data recorded physically is typically transcribed into electronic data for easier handling by computers or **Laboratory Information Management System (LIMS)**, which leads to a workflow termed ‘data entry’.

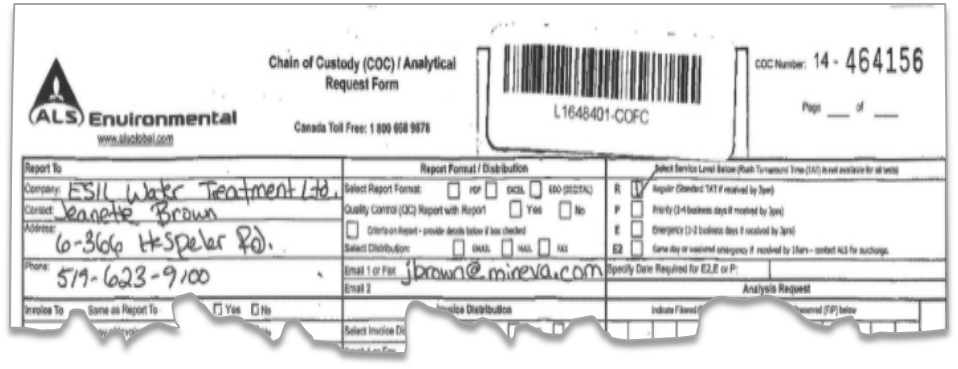


Figure 5.2 – Example of routine paperwork used by laboratories. In this case a document called a Chain of Custody form which is used for legal reasons to ensure the integrity of the sample is kept during transportation. © TAFE NSW

Physical data can be stored in:

* Filing cabinets

Electronic data can be stored in:

* Computer databases
* Spreadsheets
* LIMS (online or cloud databases)

The storage of data is a standard workflow process. A sample is worthless unless its origin and/or history are recorded. The origin of a sample is the place and time where it was taken, such as a particular work area or batch.

The history of a sample is a record of how the sample was taken, how it was transported and stored and what has been done to test it. Samples must be carefully labelled to avoid confusion and to make sure that the sample can always be linked to the place and time where it was taken.

All data obtained must be coded. This means that the data must be identified in some way so that it is linked to its origin and history. For example, if you have obtained data from testing wine bottles, when you record that data you must identify the crates or batch that each sample was obtained from.

The same applies to any equipment that are calibrated (like thermometers). These are coded so that accurate calibration records can be kept. Careful coding will give you an **audit** trail. An audit trail is a way that you can trace any sample or result back to its source.

This is particularly important for two reasons:

1. In a quality system, you must be able to prove the reliability of your test results by being able to trace back from the result to find out exactly how tests were done and how the samples were collected.
2. If there is a problem with a result, it may be necessary to take some form of corrective action. For example:
   1. If there was a food poisoning outbreak caused by salami, it would be necessary to know exactly which batch of salami caused the problem.
   2. If a customer questioned the reliability of the results of your testing, you must be able to show exactly how the results were obtained, what equipment was used and whether it was in proper working order at the time.

## Retrieving data

Data is stored for many reasons. If data is stored for a reason, then it makes sense that it may need to be retrieved for similar reasons that it was originally stored for. The data retrieval will be based on how the data is stored, so if you physically store, you will physically retrieve the data, and the same for electronic data.

Most companies have developed forms for recording and storing data as part of a Quality Assurance (QA) program. In a QA system, forms are usually coded by number or date and filed in order so they can easily be found again. The forms are usually filed in a QA filing system maintained by the plant’s QA manager. This is done so that the results can easily be retrieved when needed.

In addition to hard copy forms, much data these days is stored electronically on spreadsheets or databases to allow speedy retrieval and processing of information.

## Checking data

At some point during the workflow, the data that is stored needs to be checked to see if it is fit for purpose. This can be performed at any stage, and often at multiple stages, which makes sense.

But how do we check data? How do you check anything? Usually by comparing it to a known value, or acceptable range of values. Believe it or not, you do this all the time when you shop – the cashier will ask for money from you and you compare the stated value against the ticketed price to check the cost. This is exactly what we do in the workplace.

Checking the quality of data is part of a much bigger process called **Quality Assurance** (**QA**), as part of a work function called **Quality Control** (**QC**, although the two terms are combined and commonly called **QA/QC**). Ignoring the bigger QA/QC part at the moment, and focusing just on data checking, the theory states that there are in fact six processes (core dimensions) associated with the checking of data alone, as illustrated in the figure below.



Figure 5.3 – Checking the quality of data using the 6 data quality dimensions. © DAMA UK 2013

So, data is only useful if it is correct and presented in the appropriate format. The quality of data relies on a number of factors that include:

* correct recording of data onto primary documents such as test sheets and QC sheets
* correct spelling of names and addresses
* correct numerical data such as date of birth and driver’s licence number
* checking that the check digits are correct
* correct transcription of this data from the primary document to a secondary document or to a computer spreadsheet or database
* checking for transcription errors
* checking that all coding that links this data to a particular customer, patient or process is correct; for example, a pathology sample will be linked by at least two pieces of information such as full name of patient and date of birth
* ensuring that the sample is suitable for testing or processing
* ensuring that the correct tests were performed on the sample
* checking that QC data that may confirm the quality of the data is within limits
* checking that all sign offs and double checks have been completed

A common expression in the computer industry is ‘garbage in, garbage out!’ The computer cannot fix poor data. It will just process that data to produce ‘garbage’ results. Adopt the habit of always double checking data.

## Rectifying errors

Only by acknowledging errors and investigating them can we begin to understand the causes of problems. When you know what the causes of the problems are, you can put work procedures in place to ensure that, in the future, the quality system works more effectively.

There are a number of golden rules for handling errors in data that must be followed for an enterprise to function properly. They are not difficult rules to understand or apply and can be summed up as:

1. Have processes in place to identify the error. A process of systematic checking should discover the mistakes before they are passed onto a customer.
2. Acknowledge the mistake openly rather than cover it up. Every laboratory will make mistakes sooner or later.
3. Mistakes and errors must be promptly dealt with. This may mean amending a calculation or repeating a test.
4. The new (correct) data or result should be added to the record, and clearly linked to the original data that was found to be incorrect.
   1. The incorrect data should not be erased, but it must be made absolutely clear that it is no longer valid and a brief reason should be given for the change.
   2. Neatly crossing out a faulty result, rather than hiding it with correcting fluid allows you to keep a record of the problems that occur with testing and data processing.
5. The person making the correction must initial/sign and date the correction.
6. Reports should be issued free from erasures if possible. You don’t need to advertise your mistakes to a customer if you pick them up and can correct them before the report is issued.
7. If results have already been issued to a customer before a mistake was discovered, the customer must be promptly informed of the error and a new statement of results issued that is clearly annotated ‘Amended Result’.
8. Learn from the error and amend processes to prevent this happening again.

There are a number of reasons why data errors in the laboratory are amended in such a way as to leave both the incorrect and correct result in the records. These are:

* It will be clear if someone tries to alter the record, at a later date, for dishonest purposes.
* Correct data that is incorrectly thought to be incorrect will not be erased and lost forever!
* The causes of the problems may be properly investigated in order to prevent the mistakes from being repeated.

|  |  |
| --- | --- |
| Self-check questions icon | Self-check questions – Topic 5 |

*Check your understanding of the basic topics in this section by answering the questions below (or other questions provided by your teacher).*

1. *Why is it so important to check data quality? Give at least three reasons why.*
2. *Discuss with your teacher and provide two examples where poor data could cause problems in an analysis.*
3. *A 20mL volumetric flask is filled to the mark and weighed. This is repeated five times. Assume that the temperature is the same at each weighing. Which of the following results might be a transcription or other type of error: 19.968g, 19.994g, 19.399g, 20.013g, 20.002g. Discuss the reasons for the variation and sources of error with your teacher.*
4. *Why do you think the process of rectifying errors is a formal process?*
5. *A technician has written down the following results in the laboratory and then typed them into a table. Have any errors been made? What is the source of the error?*

|  |
| --- |
| *Notebook*  *3/5/18 Readings: SL2018-01 8.562mg/L SL2018-02 9.362mg/L*  *4/5/18 Reading: SL2018-03 4.695mg/L* |

|  |  |  |
| --- | --- | --- |
| *Date* | *SL Number* | *Reading (mg/L)* |
| *03/05/2018* | *SL2018-01* | *8.662* |
| *04/05/2018* | *SL2018-02* | *9.362* |
| *04/05/2018* | *SL2018-03* | *8.695* |

1. *Identify 4 sources of data from your workplace or campus laboratory. Indicate whether the data is in written or digital form.*
2. *What does LIMS stand for? What does it do for a laboratory?*

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