Graphs (图表), errors(误差), significant figures(有效数字), dimensions(量度) and units(单位)

This page supports the Physclips project(这个网页从于帮助阅读physclips), especially Chapter 2: Projectiles (特别是第二章 抛物体)

The first module in Physclips uses displacement-time and velocity-time graphs for a man walking in a straight line(在physclipe中 第一个模块表现的是一个人行走在一条直线上的位移时间图表和速度时间图表), so we'll begin with this animation(所以 我们从这个动画开始).

An example: Displacement-time graphs (例子 位移时间图表)

How can we keep track of this fellow?(我们怎么能一直检测这个人的路线呢) In other words(或者说), how do we show his position at any time?(我们怎么可以表现出这个人在任意时间的位置呢) The graph above answers this question(以上的图表就是这个问题的答案). The man's distance from some reference position, here the wall(这个人的移动以墙壁作为参照点), is how far he is displaced from it(位移就是从墙壁移动了多少距离). We call this displacement x(我们把它叫做位移x), where x is positive if he is to the right of the wall(在这里如果他向墙壁右侧移动x取正值). Formally, the graph shows his position as a function of time(这个图表在形式上反应了他位置关于时间的方程).

The reference for displacement is the wall, x = 0(位移的参照点是墙壁 在那里x=0). We also need a reference for time 我们同样需要一个时间参照点 . It could be the time at which we set a stop-watch ticking(它可以是我们秒表上的时间). If the watch starts at zero seconds(如果秒表起始于零妙), any time after that is positive time (t > 0)(从这一刻往后任何的时间点都取

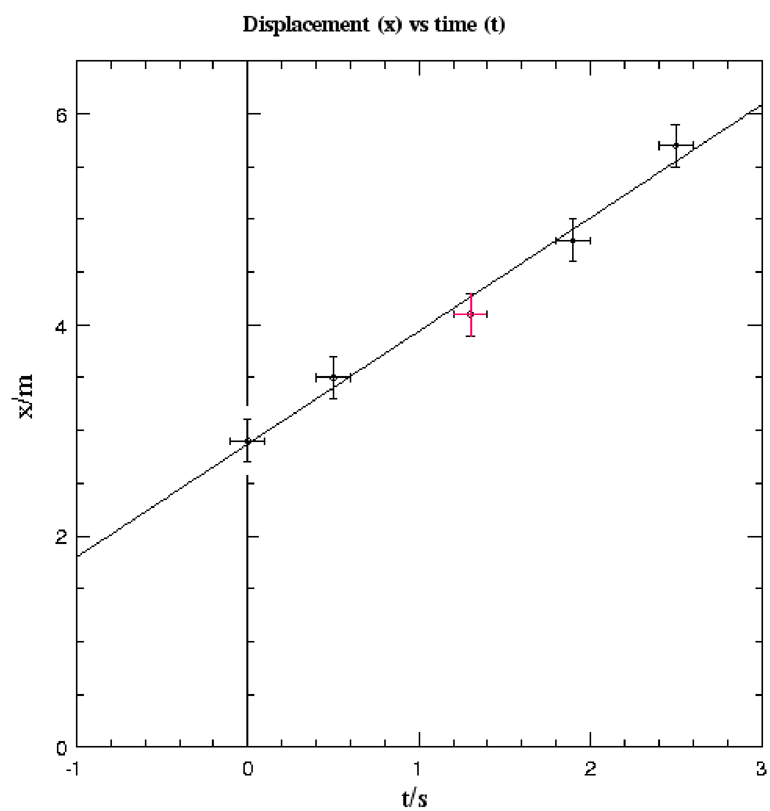
正值即 t>0). Of course physics was still happening before we set our watch(当然在我们设置我们的秒表之前物理现象还是会发生), so anything that happens before t = 0 would be represented on the negative part of the time axis(所以任何发生在t=0之前的时间点 将在时间轴上取负值).

Units on graphs(图表上的单位)

In science and engineering(在科学和工程学科中), the fundamental units for length and time are metres (abbreviation m) and seconds (s)(长度和时间的基础单位是米(缩写m)和秒(缩写s)). Multiples and submultiples (kilometre, microsecond) are used when needed(倍数和约数电位 千米 微秒 在需要的时候也会被使用). There are two common ways of representing units on the axes of graphs (here m and s)(通常有两种方式来表示图表轴上的单位). One is to write x (m) and t (s)(第一个是写做x(m)和t(s)). The disadvantage with this convention is that it may suggest that x is a function of m 这个表示的缺点是 x可能会被认为是m的函数 , and it is awkward when one really does want to plot x as a function of m(当一个人真的想把x表示成m的函数时 这是非常尴尬的).

The method used here is to plot x/m and t/s(我们这里用到的表示是x/m和t/s). This has the advantage that(它的优点是), when x is divided by a metre or t is divided by a second(当数值x除以一米或者数值t除以一秒), the result is a number(其结果是一个数字). Numbers (not quantities) are what we plot on the axes(这个数字(不是数量)就是我们画在轴上的数字): the axes really are x/m and t/s(轴上现实的真正是x除以m和t除以s), so it is a good idea to label them in this way(所以用这个方式来标示轴是很有想法的).

Errors, error bars and significant figures(误差 误差棒和有效数字)



Linear Regression y(x) = m*x + b

m	b	dm	db	chi^2	q
1.07247	2.87014	0.0986287	0.151516	1.76009	0.623658

How accurately are the data known?(已知的数据有多精确) Suppose you make the measurement x = 4.1 m by looking at a tape measure(假设你使用卷尺来测量x=4.1米). As you do so(伴随着你测量距离), you click the stopwatch(你按下秒表), which shows 1.32 seconds(时间记录1.32秒). It is difficult to define the position of a person with greater precision than about 0.2 m (很难去定义一个人的位置以0.2米的精确度), because of the relative motion of arms and legs(由于手臂和腿的相对运动), so the error in the measurement is likely to be roughly this, or greater (所以在测量中的误差可是大概和这个数值相等或者大于它). We should therefore write x = 4.1 ± 0.2 m(因此我们应当将位移写做x = 4.1 ± 0.2 m).

We might be tempted to write t = 1.32 s(你可能很想写下(t=1.32s)), because the watch is capable of measurements with this precision(因为秒表的精确度就是现实的数值). You will probably find, however, that you are not(但是你可以会发现并不是这样的). Repeated measurements of the same period (重复测量相同的时间)(eg the time it takes a second hand to pass 2 seconds on a clock(例如你用秒表测量一秒变到两秒的时间)) will not usually give the same answer(它通常不过有相同的结果), and the variation is probably about 0.1 s(变化可能是大概0.1秒). So the measurement error here is (very roughly) about 0.1 s(所以这里测量的误差 粗略上将 是0.1秒).

Now, if you write t = 1.32 s(如果你写t=1.32s), you are implying that the '2' means something(你指的是最后一位'2'是有意义的), that it is *significant(*这是有效位数*)*. You are implying a precision that you don't actually have(你使用了一个你并没有实际拥有的有效位数). So, to avoid misleading the reader(所以为了避免误导读者), you should retain only the two significant figures(你应当仅仅保留两位有效数字). Consequently(因此), this should be written (as we say) to two significant figures(这个应该被写做两位有效数字 像我们说的那样), t = 1.3 s. To make the error explicit(为了使误差更清楚), we might write(我们可以写做) t = 1.3 ± 0.1 s. (If we had done a detailed study of our timing reproducibility and found its standard error to be(如果我们通过完成详细的重复性的时间记录研究 发现它的标准误差是) 0.15 s, we could write(我们可以写做) t = 1.32 ± 0.15 s.)

How can we show the point (t,x) = (1.3 ± 0.1 s, 4.1 ± 0.2 m) on a graph(我们怎么能把点(t,x) = (1.3 ± 0.1 s, 4.1 ± 0.2 m)表现在图表

上呢)? We do this by drawing a cross(我们做了这样一个十字), whose vertical axis goes from 3.9 to 4.3 m and whose horizontal axis goes from 1.2 to 1.4 s(它的竖轴数值是从 . 到 . 米 横轴数值是从 . 秒到 . 秒). This is shown in red on the graph at right(这个显示在了右图的红色十字).

The above is only a quick sketch(以上的仅仅是快速简单的说明). For more details(对于更详细的介绍), see the notes Errors and handling them.(可以参看资料误差和误差处理)

A good plotting program(好的绘图程序)

Your computer probably came with spreadsheet software that draws graphs of the sort that administrative people like(你的电脑可能具有电子制表软件 它可以根据用戶的喜好分类绘图). That software is useful for storing the data and doing some manipulations(这些软件对于储存和管理数据是非常有用的), but the graphs it draws are unsuitable for science or engineering(但是它所画的图表并不适用于科学和工程学科).

Michael Johnston, one of our past undergraduate physics students(一个前物理系的本科学生), was frustrated with the inability of such software to draw scientific graphs and to fit simple functions appropriately(对于这类软件在绘制科学图表以及简单公式拟合方面的缺陷表示非常失望). So he wrote an application that does this(所以他写了一个程序来执行这些任务). You'll note that it draws the error bars that you enter(你将会注意到它可以将你输入的误差棒绘制出来). If you ask to fit a simple function to the plot(如果你需要绘制一个简单的拟合方程), it does a least-squares *error-weighted* fit(它能够做最小二乘法加权误差拟合): in other words(换句话说), it gives more weight to the points with small errors than to those with large errors(它给了小误差点更多的权值相比于大误差点). Here isMichael's curve-fitting program.(这里就是迈克尔的曲线拟合程序), which we use to analyse an experiment in Projectiles and which we also used to make the graph at right(我们用它来分析抛物体实验中的数据 并且用它来绘制右方的图表).

Units and dimensions (单位和量度)

What is wrong with saying 这样说有什么错
- "My height is 45°C"? Or: (我的高度是 摄氏度 或者)
- "The game lasted 15 kg"? Or: (这场游戏持续了 千克 或者)
- "The displacement is given by the weight divided by the volume squared"?(位移定义为重量每平方体积)

In each case(在每一个情况下), we mention two physical quantities that cannot possibly be equal(我们都提到了两个不可能对等的物理定量). Let's take the first(我们先来说一下这个): a height cannot equal a temperature(高度不可能对等于温度), so I cannot measure my height in degrees Celsius(所以我不可能测量我的身高用摄氏度). Let's call my height h(假设我的身高是h). I can say "h = 1.8 m"我可以说h=1.8米. I can also say that h = V/A"(我也可以说h=V/A), where V is my volume and A is my average horizontal cross sectional area(这里V是我的体积 A是我的平均横截面). In both cases(在这两个情况下), the quantity on the right hand side is a distance(等式右边的定量始终是距离), as is the quantity on the left hand side(等同与等式左边的定量).Both can be measured in metres(他们都可以用米来测量).

We shall see that this very simple idea can be quite important -- and also very useful.(我们将会看到这个非常简单的想法会是非常非常重要的—同时也非常有用)

Now the units on either side of an equation need not be the same(现在 等式两边的单位不一定相同). For instance(例如), I may write(我可以写)
1 inch = 25.4 mm.(1英寸=25.4毫米)

This equation is true.(这个公式是正确的) (In fact(事实上), it is the definition of the inch(这个是英寸的定义), a unit of length in the old British system of units(这个长度单位是英国的旧系统单位).) However(可是), this equation is different from the silly examples given above(这个方程是不同于我们上文所给的错误方程的), because both the millimetre and the inch measure length(因为毫米和英寸都可以衡量长度). We say that both sides of the equation have the **dimensions** of length(我们说等式的两边都有长度的量度). This condition must be satisfied for an equation to be true, or even to make sense(一个正确的有意义的方程必须满足这个条件). Further(此外), if equations have different units with the same dimension(如果等式中含有同一量度不同的单位), appropriate conversion factors must be included(适当的转换因子应当被提供), as is the case above(就像上诉情况一样).

Let's look at more interesting examples(让我们来看看更有趣些的例子). When we write(当我们写)
F = m**a** ,

we are specifying that the dimensions of force are those of mass times acceleration(我们声明力的量度是重量乘以加速度). The dimensions of acceleration are length, which we write as [L], divided by time [T] squared, (加速度的量度是长度 我们写作L ,除以时间 T ,的平方)so we write(所以我们写作), just for the dimensions(仅仅是为了量度):

[F] = [M][L][T]−2.

In the units of the Système International(在国际系统单位里), universally used in science(这个标准通常会在科学中使用), there are no conversion factors for the base units(基础的单位没有转换因子), so we can relate the newton(所以我们可以将牛顿表), the unit of force(力的单位), to other base units(表现成其他基础单位):
1 N = 1 kg.m.s−2.

And to use our equation once more(再用一次我们的方程), we note that(我们发现), while mass is a scalar(重量是一个标量), force and acceleration are both vectors(力和加速度是矢量), so our previous equation tells us not only that(所以我们前面的方程不仅表明了) F = ma, but that **F** is parallel to **a(**而且指明了**F**平行于**a)**.

Let's now see how the method of dimensions can be useful, via this(现在让我们通过这个来看看那度量的方便有多么有用)

Example: how does the frequency, of a pendulum depend on the length?(例子 一个钟摆的频率怎样取决于长度**)**

We know that this depends on the length(我们知道这个取决于长度), L -- a long one swings more slowly than does a short one(一个长的钟摆摆动比一个短的钟摆要慢). It also depends on the strength g of the gravitational field (它也取决于重力场强度g)-- it won't swing at all without one(没有这个它根本不会摆动). Does it also depend on the mass 它也取决于重量吗 , m? On the temperature(温度), T? Let's write for the frequency(让我们写下频率), f:
f = N.La.gb.mc.Td
where N, a, b, c and d are numbers(这里N,a,b,c 和d是数字), yet to be determined(数值还没被决定). Of course(当然), we can analyse the dynamics of the pendulum and determine them(我们能够通过分析钟摆的运动来推到出这些数字), but let's see how far we get just by considering the dimensions(但是 让我们看看从量度的角度上我们可以走多远). Frequency has units of "per second" so it has the dimensions of reciprocal time(频率有一个单位‘每秒’所以它与时间有相反的量度), T−1 . So, setting the dimensions equal on both sides, we have(所以 通过调整两边的量度 我们得到了):

T−1 = N.La.(L.T−2)b.Mc.Temperatured
For this equation to be true(为了让这个等式成立), each dimension must occur, to the same power, on each side(每一个量度在等式两边的作用要相同). So, considering each dimension(所以考虑到每个维度), the exponent gives us an equation to be satisfied(指数必须忙足方程). If we start with time T(我们从时间T开始), we see that it appears to the −1 power on the left(我们看到在左边他的指数是-1), and to the −2b power on the right(在右边指数是-2b), so we have(所以我们有)
[T] −1 = −2b
where the arrow means "implies"(在这里箭头代表着’暗指’). For the other dimensions(对于其他的量度), we get(我们有)
[L] 0 = a + b
[M] 0 = c
[Temperature] 0 = d.

Now the last two shouldn't surprise us(现在最后两个等式不应该让我们奇怪). A more massive pendulum experiences a greater gravitational force but it also requires more force to accelerate(一个更重的钟摆具有更大的重力但是它也需要更大的力去加速), so we should not be surprised that the dimensions of the problem tell us that c = 0(所以我们不应该惊奇于量度告诉我们c=0), ie that these effects cancel out: the frequency does not depend* on the mass of the pendulum (例如这些效果会相互抵消 钟摆的频率不取决于钟摆的质量). Similarly(于此相似), we see that d = 0(我们看到d=0), but we should not be too surprised that a hot pendulum and a cold one swing at the same frequency(但是我们不应该太惊奇与一个热的钟摆与一个冷的钟摆有相同的摆动频率) -- unless of course the temperature changes the length perceptibly(当然出了温度改变钟摆长度的时候).

The other two equations tell us that(另外两个方程告诉我们) b = 1/2, and that (并且)a + b = 0, so(所以) a = −a = −1/2. So(所以), substituting in our original equation for the frequency(带入我们原来的频率方程),
f = N.L−1/2.g1/2 = N(g/L)1/2.

We still don't know the value of the number N(我们还是不知道N的数值), and cannot get it from the information we have been given here(并且不能从它已经给的信息中求得). (It is 1/(2*π), in case you were wondering(如果你好奇的话 我可以告诉你它是1/(2*π)).) However(可是), we do know that(我们确实知道), all else equal(其他都是相等的), the frequency is proportional to the reciprocal of the square root of the length(频率是正比于长度平方根的倒数的). To halve the frequency of pendulum(要把钟
长

摆的频率分一半), make it four times as long(就把他曾　四倍).

* I raise a couple of tiny caveats(这里有几条附加说明), to preempt the pedants(用来应答一些学究). For a pendulum whose mass is comparable with the that of the planet upon which it is mounted(对于一个重量可比拟于它所在的行星的重量的钟摆来说), the pendulum mass does appear(钟摆的重量M会出现在方程里) -- or at least the ratio of these two masses appears(或者至少两个质量的比例会出现). Further(此外), we have cheated a little on the temperature(我们在温度方面的表示不完全正确), because we could write temperature in units of energy(因为我们可以把温度表现成能量). Doing so(这样做的话), the conversion factor would be Boltzmann's constant(转换因子就是玻尔滋蔓常数), whose very small size would give us the clue that temperature is only relevant in mechanics for objects of molecular size (这个非常小的常数向我们暗示着　仅仅当物体接近分子尺寸的时候温度才在机理中起作用). And on this molecular scale we should often need to use quantum mechanics rather than Newtonian mechanics(在分子量级下　我们常常需要用量子力学而不是牛顿力学).

Other units(其他单位**)**

With rare exceptions(出了在个别情况下), scientists use the **SI system of units(**科学家都会使用**SI**单位系统**)**. (SI stands for Système International d'Unités(SI代表着国际标准单位).) This system is based on the **kilogram** for mass(这个系统是基于千克　质量　), the **metre** for length(米　长度　), the **second** for time(秒　时间　), the **ampere** for electric current(安培　电流　), the **kelvin** for temperature(开尔文　温度　), the **mole** for chemical quantities(摩尔　化学数量　) and the **candela** for luminous intensity(坎德拉　照明强度　). Other systems are the **British imperial system** and **natural units(**其他的系统有英国度量系统和自然单位**)**.

Physclips is a scientific presentation(Physclips是一个科学介绍), and we use only the SI(我们仅仅使用SI国际单位). If you encounter problems stated in other units(如果你在陈述其他单位的时候遇到了问题), the simplest procedure is often to translate the problem into SI(那么最简单的方法常常是把这个问题变成国际单位), solve it(解决它), then translate the back(然后再把单位变回来). This sounds like extra work(这听起来像是额外的工作), but it is usually much less than the extra work required in using the imperial system of units(但是这通常是比继续使用英制单位需要更少的额外工作), which has internal conversion factors(英制单位具有内部转换因子).

In the United States of America(在美国), Liberia(利比亚) and Myanmar(和缅甸), the **British imperial system** is the official system(英制系统是官方系统). This system used to be much more widespread(这个系统过去有着很广泛的应用), and vestiges of it remain in other countries that are in the process of 'going metric'(它在那些依然经过公制化的国际尚有余温), ie converting to the SI(公制化例如转向国际单位).

Dealing with or converting from the imperial system usually involves just a multiplictaive factor(处理或者转换英制系他通常需要的仅仅是一个乘数因子). For instance(例如), the inch(英寸), an imperial unit of length(一个英制长度单位), is officially defined to be equal to 25.4 mm(官方定义是25.4毫米). These multiplications can become awkward in some cases(这些乘数因子在某些时候是相当麻烦的): consider this imperial unit of thermal conductivity(设想一下热传导率的英制单位), one British Thermal Unit per second per square foot per degree Farenheit per inch(一英制热每秒每平方英尺每华氏度每英寸). One can see why it exists(它有存在的理由), but it is ugly and inconvenient(但是它的确很丑也不方便). (For comparison, the SI unit thermal conductivity is W.m−1.K−1.(相比而言　国际单位热传导率是W.m−1.K−1))

Some confusion arises, however, because of the different colloquial use of **units of mass and force** in the SI and imperial system(可是　一些混淆出现了　因为对于质量单位和力量单位不同的习惯定义). In the imperial system(在英制系统中), the unit of force is the pound-force(力的单位是磅力), or sometimes(或者有些时候), as in many American physics text books(就像有些美国物理书中的), as just the pound(仅仅是磅). The unit of mass in the imperial system is the **slug(**质量的英制单位是斯　斯勒格　**)**, which is a mass that is accelerated by one pound at one foot per second per second(这个单位是单位质量即被一磅力加速一英尺每平方秒). The slug is 14.5939 kg.(斯是14.5939千克) These equations(这些方程), which are definitions(它们是定义), allow us to compare the units of mass and force(准许我们去比较质量和力的单位):

SI(国际单位)

Unit of force(力的单位) = 1 newton = 1 kg.m.s−2

Imperial(英制单位)

Unit of force(力的单位) = 1 pound = 1 slug.foot.second−2

In imperial units, the gravitational acceleration is 32 feet.second−2(在英制单位里　重力加速度是32英尺每平方秒). Consequently(因此), a slug weighs 32 pounds(一斯是32磅).

The slug is very rarely used(斯很少被使用). Pound is used colloquially as a unit of quantity -- a pound of apples colloquially means a quantity of apples that weighs a pound-force (at the earth's surface)(磅一般被用作数量单位——一磅苹果通常代表着一定量的苹果重力是一磅　在地球表面上　). There is another imperial unit of force(这里还有另一个英制力学单位), the **poundal(**磅达**)**. This is defined as the force required to accelerate at one foot.second−2 a mass whose weight is one pound(它被定义成一磅重的质量被加速到一英尺每平方秒). So a pound is 32 poundals(所以一磅是32磅达).

The units mentioned above are related to features of the earth (以上提到的单位是和地球的特征相结合的)(its circumference originally determined the metre, and the second is related to the day(地球的圆周根本上决定了米　而秒是和天有关)) or of artifacts on earth(或者地球上的人为定义), such as the standard kilogram(例如标准的千米), or of particular substances(或者特定的物质), especially water(特别是水). The laws of physics and combinations of them yield **natural units(**将物理定律和它们结合起来就产生了自然单位**)**, which are used by some theoretical physicists(这个单位会被一些理论物理学家使用), especially cosmologists(特别是宇宙学家). The speed of light, for instance, is taken as the unit for speed(例如光速会被用为速度单位). Although this makes equations look simple these units are, in general, inconvenient for measurement(虽然这样会让公式变得简单　但是也会让测量变得不方便). For instance(例如), the natural units of length and time are inconveniently small(自然单位的长度和时间非常小　不方便) (The Planck length is 1.6 x 10-35 metres(普朗克长度是1.6 x 10-35 米), the Planck time is 5.4 x 10-44 seconds(普朗克时间是5.4 x 10-44　秒)). See The Planck scale for more detail(详见普朗克计量).
