Expt. 1 Measurement of basic parameters of mechanics

Ⅰ. Purpose

1) Master the use of conventional measuring instruments by measuring the density of regular-and irregular-shaped objects;

2) Measure the local acceleration due to gravity using the adjustable pendulum.

Ⅱ. Apparatus

Vernier calipers, micrometer screw gauge, physical balance, adjustable pendulum, millisecond meter, thermometer, digital display caliper, pycnometer.

Ⅲ. Principle

1. Measurement of the density of a solid substance (regular shape)

Assume that the mass of a uniform substance is m and the volume is V, so that the density is $\rho = m/V$. For a regular-shaped substance, m can be measured by using the physical balance, and V can be obtained indirectly by calculation of direct measurement with appropriate length measuring instruments, e. g. , vernier calipers or micrometer screw gauge.

2. Measurement of the density of a substance (irregular shape)

For the irregular-shaped substance, V can be determined indirectly by Archimedes' principle. If the weight of the substance is $W_1 = m_1 g$ in the air and $W_2 = m_2 g$ under the liquid and we assume the density of the liquid is ρ' then the density of the measured substance should be

$$\rho = \frac{m_1}{m_1 - m_2}\rho' \tag{1}$$

When we use water as the medium and measure an irregular-shaped substance of density less then 1, we first determine the actual mass of the object and hang a weight underneath it, then immerse the weight completely to get the apparent mass m_2 of the system, as shown in Fig. 1. We then immerse the system completely to get the apparent mass m_3. The density of the object is given by

$$\rho = \frac{m_1}{m_2 - m_3}\rho' \tag{2}$$

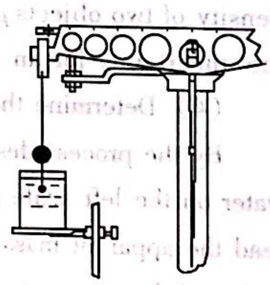

Figure 1 Measurement of the less-than-1 density material

3. Measurement of the density of granular matter

Using pycnometer and distilled water the density of granular materials can be measured. The principle is still $\rho = m/V$, where the volume V needs to be obtained indirectly. There is a capillary in the cap of pycnometer. If the pycnometer is filled with water, then put on the cap, the excessive water will overflow. So the volume of matter in the pycnometer is always constant. In consequence, determine the mass of the granular matter measured m_1, the mass of pycnometer filled with water $(\rho_0 = 1)$ m_2, and the mass the pycnometer filled with water and granular matter m_3. Then the mass of water overflowed from the pycnometer is $m_1 + m_2 - m_3$, and the volume of the overflowed water is equal to that of m_1. So the density of the measured granular matter is:

$$\rho = \frac{m_1}{m_1 + m_2 - m_3}\rho_0 \tag{3}$$

4. The measurement of the acceleration due to gravity g

Acceleration of gravity g is an important physical parameter in actual scientific research and manufacturing work. In this experiment, the measurement of the acceleration due to gravity can be done quickly and exactly by using the adjustable pendulum of which the exterior is shown in Fig. 2.

According to the formula of vibration cycle of pendulum $T = 2\pi\sqrt{\frac{L}{g}}$, when the pendulum lengths are L_i and L_j respectively, we can deduce:

$$g = \frac{4\pi^2(L_i - L_j)}{T_i^2 - T_j^2} \tag{1 - 4}$$

Ⅳ. Experimental

1. Measure the density of a solid using the physical balance

(1) Adjust the horizontal bolt of the balance; make sure the air bubble is in the centre of the spirit level and the base plate of the balance is horizontal.

(2) Zero the vernier to the left side of the beam. If the pointer is not central you should adjust the balance bolt and repeat this process, until the index pointer is at the centre of the dial.

(3) Determine the density of the regular-shaped substance: put the object $(\rho > 1)$, such as aluminum pieces or a steel ball, on the left scale pan and weights into the right pan. When the balance balances, read the number on the weights and vernier to give the mass of the object m_1. Determine the volume of the aluminum pieces using vernier calipers, and the volume of the steel ball using the micrometer screw gauge, using the density definition formula calculate the density of two objects ρ also calculate the uncertainty range of the density, using the definition of the uncertainty for an indirect measurement.

(4) Determine the density of an irregular-shaped substance $(\rho < 1)$:

By the process described above determine the mass of the object m_1; place a beaker filled with water on the left scale pan, immerse the weight linked with the object completely into the water, read the apparent mass m_2 and immerse the system of weight and object completely into the water and read the apparent mass m_3. From equation (3), determine the density, and work out the uncertainty of the result.

2. Measure the density of granular matter

based on the Archimedes principle, design procedures and measure the density of granular material using pycnometer and distilled water. Note: wipe off the water on the pycnometer each time.

3. Measure the local acceleration due to gravity by using the adjustable pendulum

In this experiment, the limit of intrinsic error of the ruler, which is used in measuring the pendulum length, is 0. 02 mm, and that of the millisecond meter is 0. 1 ms.

(1) The pendulum length differences $\Delta L = L_i - L_j$ should be chosen as 10 cm, 30 cm and 50 cm, in order to determine the effect of ΔL on the final precision of your measured value of g.

(2) Measure the period of the vibration of the simple pendulum, by the spreading method, which is: measuring 10 periods to give a good average for 1 period.

(3) Using equation (4) determine the local acceleration due to gravity "g" calculate the uncertainty range due to the precision of the apparatus.

Notes:

(1) Make sure that angle of swing of the simple pendulum is less than 5°and that it swings in a single plane.

(2) When changing the pendulum length, relax the screw of the line clamp. Tighten it again when making a measurement.

V. Questions

1. You are given a piece of alloy made of gold and copper. Describe how you could determine the ratio of gold to copper W_{Au}/W_{Cu} using the physical balance. Assume that the density of gold ρ_{Au}, the density of copper ρ_{Cu} and the density of water are known.

2. What kind of method could be used to increase the precision of the measurement of g, in this experiment?

实验一 力学基本量测量

一、实验目的

1）通过测定规则与不规则形状物体的密度，掌握常规测量工具的使用，完成长度及质量两个基本量的测量，在实践中掌握“不确定度”理论；

2）利用“可变摆长测 g 仪”测定本地的重力加速度，用“延展法”完成时间基本量的测量。

二、实验仪器

游标卡尺、螺旋测微尺、物理天平、可变摆长测“g”仪、毫秒计、温度计、比重瓶。

三、实验原理

1. 固体（规则形状）密度的测量

设物体的质量为 m，均匀分布，体积为 V，则其密度为 $\rho = m/V$。对于规则形状的物体，m 可以利用物理天平直接测量，V 可以使用长度测量仪器如游标卡尺、螺旋测微尺，经过间接测量的方法确定。

2. 固体（不规则形状）密度的测量

对于不规则形状物体，其体积 V 可以根据阿基米德原理间接测定。

如果物体的密度 >1，其在空气中和完全浸在液体中所测得的重量分别为 $W_1 = m_1g$ 和 $W_2 = m_2g$，设液体的密度为 ρ'，可推得被测物体的密度为

$$\rho = \frac{m_1}{m_1 - m_2}\rho' \tag{1}$$

如果物体的密度 <1，并以水为媒介测其密度时，则应首先确定被测物体的实际质量 m_1，然后在被测物下方用细线连接一重坠，并使重坠完全浸入液体中，称出此时两个物体的视质量 m_2，如图 1 所示。最后将被测物体和重坠同时侵入液体中，称出此时的视质量 m_3，可推得被测物体的密度为

$$\rho = \frac{m_1}{m_2 - m_3}\rho' \tag{2}$$

3. 散体（颗粒）密度的测量

利用比重瓶和蒸馏水可以测量不溶于水的粉末、颗粒等单体较小物质的密度。其基本原理仍是 m/V，体积 V 要间接获得。比重瓶的瓶盖上有一个毛细管，当比重瓶注满水并盖上瓶盖时，多余的水就从毛细管溢出，这样瓶内水（或加上待测固体）的体积总量是固定的。依次测出待测颗粒物质的质量 m_1、盛满水后比重瓶和水的总质量 m_2，以及装满水的瓶内再

加入颗粒物质后的总质量 m_3。则被颗粒排出比重瓶的水的质量是 $m_1+m_2-m_3$，排出水的体积就是质量为 m_1 的颗粒物质的体积。所以，被测物体的密度为：

$$\rho = \frac{m_1}{m_1+m_2-m_3}\rho_0 \tag{3}$$

4. 重力加速度"g"的测量

重力加速度 g 是科研、生产中时常用到的重要物理参量。本实验所采用的可变摆长测"g"仪可以快速而准确地测定当地的重力加速度，其外形结构如图 2 所示。

根据单摆的振动周期公式 $T=2\pi\sqrt{\dfrac{L}{g}}$，当单摆的摆长分别为 L_i 与 L_j 时，可推导出：

$$g = \frac{4\pi^2(L_i-L_j)}{T_i^2-T_j^2} \tag{1-4}$$

四、实验内容及步骤

1. 利用物理天平测量固体密度

（1）调整天平底座的水平螺钉，使水准器中的气泡位于中心，天平底板水平。

（2）把游码移到横梁左端零线上，顺时针打开旋钮开关支起横梁；如天平不平衡，应关闭天平。调节平衡螺母，重复此步骤直至指针指到标牌中点为止。

（3）首先测定规则形状物体的密度：将 $\rho>1$ 的被测物（铝件、钢球）分别放在天平左边称盘中，砝码放在右边称盘中。天平平衡时，由固定砝码和游码之和确定被测物体的质量 m_1。用游标卡尺测定铝件的体积、用螺旋测微尺测定钢球的体积，再由密度的定义式分别确定两物体的密度 ρ，应根据间接测量量不确定度的定义式分别确定两个被测物体的密度的不确定度范围。

（4）测定 $\rho<1$ 的形状不规则物体的密度：同上步骤，测定待测物体的质量 m_1；再将盛水的烧杯放置在天平左边托架上，然后将与被测物连接的重坠完全浸入水中，测出此时的视质量 m_2；最后，将被测物体和重坠一同完全浸入水中，测出此时的视质量 m_3。由公式（2）确定被测物体的密度，并确定结果的不确定度范围。

2. 利用比重瓶测量颗粒物质的密度

利用比重瓶和蒸馏水测量给定颗粒物质的密度。注意：每次测量质量前，要擦干净比重瓶上的水。

3. 利用可变摆长测"g"仪测定本地重力加速度

实验中，测量摆长变化所用的高度尺的允许误差极限为 0.02mm；用于摆动周期测量的《通用电脑式毫秒计》的允许误差极限按 0.1ms 计算。

（1）摆长的变化量 $\Delta L=L_i-L_j$ 分别选择为 10cm、30cm、50cm，以判定 ΔL 的大小对测量结果精度的影响。

（2）采用"延展法"测量单摆的振动周期，即：通过测量单摆 10 个摆动周期所用时间，而确定一个周期的大小。

（3）由原理公式确定本地重力加速度 g 的量值，并根据测量仪器精度确定测量结果的不确定度范围。

注意：

（1）测量单摆的振动周期时，应保证单摆的摆角≤5°，并保持单摆在同一平面内摆动。

（2）改变摆长时，必须先将仪器上的夹线器的螺丝放松。正式测量时，则应将夹线器的螺钉固紧，以保证摆长变化的准确。

五、思考题

1. 已知：金和铜材的密度分别为ρ_{Au}和ρ_{Cu}，现有一块合金是由金和铜材两种成分合成，用公式说明如何用物理天平测定合金中金、铜重量之比$\frac{W_{Au}}{W_{Cu}}$。设ρ_{Au}、ρ_{Cu}及水的密度已知。

2. 为了提高“g”值的测量精度，在实验中应注意什么问题？

实验一　力学基础实验数据表格

1. 固体密度的测量

①密度 >1 的铝件的密度(游标卡尺测量其体积)

铝柱体积公式：$V=\frac{\pi}{4}D^2H-\frac{\pi}{4}d^2h$　卡尺允许误差(极)限 $\Delta_{\text{ins}}=0.02\text{mm}$

分布特性为均匀矩形分布、置信度 100%，标准不确定度对应的包含因子 $k=\sqrt{3}$

参量 / 序数	D/mm	H/mm	d/mm	h/mm
1				
2				
3				
4				
5				
6				
7				
平均值$\bar{x}$/mm				
实验标准偏差 $S(\bar{x})$/mm				
不确定度 A 类分量 u_A/mm				
不确定度 B 类分量 u_B/mm				
合成标准不确定度 u_C/mm				
直接测量量结果$\bar{x}(u_C)$/mm				
间接测量量结果 $V(u_V)$/mm^3				

注意：标准不确定度首位为 1 或 2 时，有效数字取两位。其他情况取一位有效数字铝柱质量 m 的测量：天平型号：TW—05；称量 500g、最小分度值 0.05g。

$\Delta_{\text{ins}}=0.05\text{g}$　　$u_m=u_B=\Delta_{\text{ins}}/k$　　包含因子　$k=1.654$

$m(u_m)=$＿＿＿＿＿＿　　铝柱密度 $\rho(u_\rho)=$＿＿＿＿＿＿

②密度 >1 的钢珠密度的测量(千分尺测量其体积)

钢球体积公式：$V=\pi D^3/6$　　　　螺旋测微尺的允许误差限为 0.004mm

分布特性为均匀正态分布、置信度 95.45%，标准不确定度对应的包含因子 $k=2$

螺旋测微尺零读数 x_0(已定系统误差)：

测量前＿＿＿、＿＿＿、＿＿＿；测量后＿＿＿、＿＿＿、＿＿＿；

零读数平均值$\bar{x}_0=$＿＿＿ mm

直径的测量值 x/mm（共需测 7 次）	1.	3.	5.	7.
	2.	4.	6.	
直径的平均值 $\bar{x}$/mm				
标准偏差 $S(\bar{x})$/mm				
不确定度 A 类分量 u_A/mm				
不确定度 B 类分量 u_B/mm				
合成标准不确定度 u_C/mm				
直径 $D=(\bar{x}-\bar{x}_0)(u_C)$/mm				
体积 $V(u_V)\mathrm{mm}^3$				

钢珠质量 $m(u_m)=$________　　钢珠密度 $\rho(u_\rho)=$________

③密度 <1 的聚丙烯测件的密度(阿基米德原理的方法)

天平型号:TW—05;称量 500g、最小分度值 0.05g　包含因子 $k=1.654$

水温 $t=$________℃　　水的密度 $\rho'=$________ $\mathrm{g\cdot cm^{-3}}$

待测物体在空气中的质量　m_1/g	
视质量　m_2g	
视质量　m_3/g	
物体密度　$\rho=m_1\rho'/(m_2-m_3)/\mathrm{g\cdot cm^{-3}}$	
相对不确定度　$E(\%)$	
绝对不确定度　$u_p=\rho\times E/\mathrm{g\cdot cm^{-3}}$	
物体密度　$\rho(u_\rho)/\mathrm{g\cdot cm^{-3}}$	

推导相对不确定度表达式　$E=$____________________。

2. 测量本地重力加速度(可调摆长测"g"仪)

ΔL/cm	L_i/cm	T_i/s	L_j/cm	T_j/s	L_i-L_j/cm	$T_i^2-T_j^2/\mathrm{s}^2$	$g=\dfrac{4\pi^2(L_i-L_j)}{T_i^2-T_j^2}/\mathrm{cm\cdot s^{-2}}$
10.000							
30.000							
45.000							

此实验不考虑不确定度的计算,但应注意各直接测量量有效数字的正确表达。

思考题