

IV. *An account of some Experiments made on the 27th day of April, 1719. to find how much the Resistance of the Air retards falling Bodies.* By J. T. Defaguliers, LL. D. & F. R. S.

I Took 12 Balls (six of which were solid Leaden Globes of about 2 Inches Diameter; three hollow Glas Balls of about 5 Inches Diameter; and three light Pastboard hollow Globes of about the same Diameter) and having carried them to the upper Gallery in the Lanthorn, on the Dome of St. Paul's Church, I caused them to fall down by two at a time, in the following manner;

First, a Leaden Ball and a Glas Ball.

Secondly, a Leaden Ball and a Glas Ball.

Thirdly, a Leaden Ball and a Glas Ball.

Then I let fall in the same manner the three other Leaden Balls, each with a Pastboard Ball.

After that, having the Leaden and Pastboard Balls brought up again, I repeated the Experiment twice more with a Leaden and Pastboard Ball: then I made the Experiment twice more with a Pastboard Ball alone, to see how long it would be in falling.

Upon the whole it appeared that the Leaden Balls were a very little longer than $4\frac{1}{2}$ Seconds in falling; the two largest of the Glas Balls 6 Seconds, and the Pastboard Balls $6\frac{1}{2}$ Seconds.

The height of the Gallery, from whence the Bodies fell, was 272 Foot above the Pavement of the Church (then cover'd with Boards) upon which they fell.

The times of the Falls were taken two ways above, viz. with a Wheel-Chronometer, which measures a
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small part of Time accurately, nearer than to a quarter of a Second (made and contriv'd by Mr. *George Graham*, an ingenious Clock-maker) and with an $\frac{1}{2}$ Second Pendulum: And the differences of Time between the fall of the Leaden Balls and the other Balls were taken below by the President, *Martin Folkes* Esq; F.R.S. and another Person, who all agreed in their Observations of the Time, which they made each with an half Second Pendulum.

The following Table gives the Marks, Weights, and Diameters of the several Balls, in three Columns.

| <i>Leaden Balls</i> | <i>Troy Weight.</i> l. oz. d. | <i>Diameters in Inches</i> and Decimals. |
|--------------------------|----------------------------------|---|
| 1c | 2 : 1 : $\frac{1}{2}$ | 2 , 1 |
| 2c | 1 : 11 : 4 | 1 , 99 |
| 3c | 1 : 11 : 12 | 2 , 0 |
| 4c | 1 : 11 : 12 | 2 , 0 |
| 5c | 1 : 11 : 12 | 2 , 0 |
| 6c | 1 : 10 : 0 | 1 , 98 |
| <i>Plastboard Balls.</i> | | |
| A | 0 : 3 : 6 | 5 , 5 |
| B | 0 : 1 : 14 | 5 , 1 |
| C | 0 : 1 : 17 | 5 , 1 |
| <i>Glass Balls.</i> | | |
| D | 0 : 3 : 13 $\frac{1}{2}$ | 3 , 9 |
| E | 0 : 5 : 3 $\frac{1}{2}$ | 5 , 42 |
| F | 0 : 6 : 0 $\frac{1}{2}$ | 5 , 55 |

N.B. The Polar and Equatorial Diameters of the Glass Balls being different, I have set down a Mean Diameter for each of them; the true Diameters are thus, of D 4 & 3,8. of E 5, 6 and 5,25. of F 5,7 & 5,4 Inches.

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The particular Experiments are as follows.

Experiment I. Fall of 1c and D.

c fell by the Pendulum in $4\frac{1}{2}''$.

The Fall of D was so near it, that the Difference was not taken either above or below.

Experiments II. Fall of 2c and E.

2c fell by the Chronometer in 5'', by the Pendulum in $4\frac{1}{2}''$.

Time of the fall of E not taken above.

The Difference taken below $1\frac{3}{4}''$.

Experiment III. Fall of 3c and F.

3c fell by Chronometer in $4\frac{1}{2}''$, by Pendulum in $4\frac{1}{2}''$.

F fell in Six Seconds.

Difference taken below was $1\frac{1}{2}''$.

Experiment IV. Fall of 4c and A.

4c fell by Chronometer in $4\frac{3}{4}''$, by Pendulum in $4\frac{1}{2}''$.

A fell in $6\frac{1}{2}$ Seconds.

Difference taken below = 2''.

Experiment V. Fall of 5c and B.

We made no Observation above nor below.

Experiment VI. Fall of 6c and C.

6c fell by Chronometer in $4\frac{3}{4}''$, by Pendulum in $4\frac{3}{4}''$.

C not taken above.

Difference below = $2\frac{1}{4}''$.

Experiment VII. Fall 1c and B.

1c fell by Chronometer in $4\frac{3}{4}''$, by Pendulum in $4\frac{3}{4}''$.

B not taken above.

Difference taken below $2\frac{3}{8}''$

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Experiment VIII. Fall of *5c* and A.

5c fell by Pendulum in $4\frac{3}{4}$ ".

A fell foul and so was not observ'd at all.

Difference taken below 2".

Experiment IX. Fall of B alone.

by the Chronometer in $6\frac{1}{2}$ ", by the Pendulum in $6\frac{1}{4}$ ".

Experiment X. Fall of C alone

by the Chronometer in $6\frac{1}{2}$ " by the Pendulum in $6\frac{1}{4}$ ".

By *Galileo's* Theory the Lead, which was $4\frac{1}{2}$ " in falling, must fall 4 Foot the first $\frac{1}{2}$ ", or 16 Feet the first Second, which amounts to 324 Feet in $4\frac{1}{2}$ ". But as the Sound of the Ball (as it struck the Bottom) by which we reckon'd our Time, had 272 Feet to move, we must abate a $\frac{1}{4}$ of a Second nearly, (supposing Sound to move one Mile in $4\frac{1}{2}$ ") which will take away 35 Feet, that the Body must have fallen in the last $\frac{1}{4}$ of a Second, and reduce the number of Feet to 289 : so that the Lead will have only fallen 17 Feet short of the Theory, which must be attributed to the Resistance of the Air.

The large Glass Ball in the 6 Seconds of its Fall, wou'd in a *Vacuum* go thro' 576 Feet : but taking away the last $\frac{1}{4}$ of a Second or 47 Feet, for motion of Sound, it must only fall 529 Feet in *Vacuo*. Now since it fell but 272, there have been 257 Feet taken off from the Fall by the Air's Resistance.

Likewise the Pastboard Ball in $6\frac{1}{2}$ Seconds must have fallen 676 Feet : but deducting the last quarter of a Second or 51 Feet for the motion of the Sound, there remains only 625 Feet for its fall in *Vacuo*. But as it fell only 272 Feet, we must allow a Retardment of 353 Feet for the Resistance of the Air.

At a mean we may call the weight of the Glass Ball 5 oz. *Troy*, and its Diameter 5 Inches and $\frac{1}{2}$; and the weight of the Pastboard Ball 2 Ounces *Troy*, and a little more than 5 Inches Diameter.

The Lead Balls all fell within near a Foot of one another, and made an impression in the Boards of about $\frac{1}{2}$ of their Depth.

The Barometer stood at 30, 1 Inches, and the Mercury was very Convex, and therefore inclined to rise still.

A further Account of Experiments made for the same purpose, upon the 27th Day of July last. By the same.

HAVING found by our former Experiments, that thin Glass Balls, and even Balls of pasted Paper, were too heavy to make so considerable a Difference between the time of their Fall and the fall of Leaden Balls, that it might be easily Observ'd; I contriv'd a way to make dryed Hogs Bladders perfectly round, by blowing them (when moist) within a strong Spherical Box of *Lignum Vita*, and letting them dry in the said Box before I took them out: which I did by opening the Box that screw'd in the middle, and had a hole in the Pole of one of its Hemispheres to let the Bladder pass thro', in order to tye it after blowing; and some few small holes all over the Box, that in blowing no Air might be confin'd between the inside of the Box and the Bladder, so as to hinder it from putting on a Spherical Figure. Besides I took off the ends of the *Ureters*, the Fat and a great deal of the
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upper Coats of the Bladders, before I blowed them in the Box, to render them still lighter.

The Bladders I used were some of the thinnest I cou'd find ready blown at a *Druggists*, which I moistned in Water, taking care to leave none in the inside. I chose those rather than Green ones, which in drying wou'd have stuck so fast to the inside of the Box, that it wou'd scarce have been possible to have got them out without tearing.

Having prepared five Bladders in the manner aforesaid, (which I have described the more fully to direct any body else that shou'd be willing to try the like Experiments) I took them up to the upper Gallery in the Lantern on the Top of the *Cupola* in *St. Pauls* Church; and there by a Contrivance, which I shall just now describe, I let them fall by one at a time, together with a Leaden Ball of about 2 Inches Diameter, and weighing 2 *l. Troy*: and I took notice of the time of the Fall of each Bladder, knowing by former Experiments that the Balls are about $4\frac{1}{4}$ Seconds, or a little longer time, in falling the same Height, which is 272 Feet.

The following Table, consisting of five Columns, gives in the first, the Marks of the Bladders; in the next their Diameters; in the third their Weights in Grains *Troy*; in the fourth the times of their Fall in Second Minutes of time; and in the fifth, the difference of Time between the Falls of the Leads and of each Bladder, taken below by the *President*, *Dr. Halley*, *Dr. Jurin*, *Martin Folkes Esq*; and *Mr. George Graham* the Clock-maker. The Time was taken above with *Mr. Graham's* Chronometer, (formerly described); and below with the same Instrument, and three half Second Pendulums, all which agreed very well together.

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The Experiments having been made twice over, the Table is twice set down; and those Experiments in which the Bladders fell streight down, and the most regularly, have this Mark before them (*).

| <i>Marks.</i> | <i>Diameters in Inches</i> | <i>Weight in Grains Troy</i> | <i>Time of the whole Fall</i> | <i>Diff. between the Lead and Bladder.</i> |
|---------------|--------------------------------|----------------------------------|-----------------------------------|--|
| A | 5,3 | 128 | 19 $\frac{3}{8}$ " | 14 $\frac{1}{8}$ Seconds. |
| *B | 5,193 | 156 | 17 $\frac{1}{4}$ | 12 $\frac{3}{4}$ |
| C | 5,33 | 137 $\frac{1}{2}$ | 18 $\frac{3}{4}$ | 14 $\frac{5}{8}$ |
| D | 5,26 | 97 $\frac{1}{2}$ | 22 $\frac{1}{8}$ | 17 $\frac{5}{8}$ |
| *E | 5,02 | 99 $\frac{1}{8}$ | 21 $\frac{5}{8}$ | 17 |
| *A | | | 19" | 14 $\frac{1}{2}$ |
| B | | | 18 $\frac{5}{8}$ | 14 $\frac{1}{4}$ |
| *C | | | 18 $\frac{3}{8}$ | 14 |
| D | | | 24 | 19 $\frac{1}{8}$ |
| E | | | 21 $\frac{1}{4}$ | 16 $\frac{5}{8}$ |

The Diameters and Weights may be relied upon, being taken the Day that the Experiments were made, and the Day after; but the Diameters and Weights taken 10 Days before, not agreeing with these, I have left them out. For the Bladders by drying had lost of their Weight, and altered their Diameters.

As the Necks of the Bladders in drying shrink, so as to open a little, they must be blown before each Experiment. And for the manner of letting them fall exactly in the same Instant of time, it is described by Figure II, in which

A, A, A A, is the Hole through which the Bodies fell: 1, 2, is a Board laid over the Hole. G, D, D is another Board fixt to the first Board by the two Wood-Screws D, D, with a Pulley G at the other end of it, over the Hole. W is a two Pound Ball of Lead fastned

fastned to a strong Thread, which going over the Pulley is stretched horizontally from G to the Nails F; to which it is fastned, so as to be about a quarter of an Inch above the Board.

B is one of the Bladders, hanging with the Neck or heaviest part downwards, by means of a Loop of fine Thread as E H, which goes over the Horizontal Thread G E F. Now when with a pair of Scissars the Thread of the Lead (which in all is but one Foot long) is cut just at E, before the Loop of the Bladder, the Lead pulling away the String the Loop of the Bladder slips off the remaining Thread F E, and begins to fall exactly in the same Instant as the Lead: But if the Thread should be cut between E and F, as the Lead falls its Thread might give the Bladder an oblique Direction.

He that observes the time either with a Pendulum or Chronometer may take it very exactly, by seeing the motion of the Scissars as they cut the Thread.

N. B. As the Diameters of the Bladders were taken by wrapping a Thread twice round them, and something must be allowed for the thickness of the Thread; I have here under set down the Diameters of the Bladders, as corrected by that Allowance. *Viz.* A 5,28 Inches; B 5,19; C 5,30; D $5\frac{1}{4}$; and E just 5 Inches in Diameter.

The Bladder E was rough, with several Wrinkles and inequalities, which made it be longer in falling than it ought to have been, according to its Diameter and Weight.

A Pail of Water thrown down met with such a Resistance in falling 272 Foot thro' the Air, that it was all turn'd into Drops like Rain.

F I N I S.

ERRATA. *Phil. Transf.* N^o. 357. Page 848. l. 22. lege ab *b* 11' 32".
 N^o. 359. p. 932. l. 17. lege $\frac{1}{2}$ 0", 1. p. 937. l. 5, 6. lege restituan-
 tur. Et Systole Arteriarum cum Cordis Diastole duratione convenit.
 N^o. 361. p. 1005. l. 16. read, *proof of the falsity of the Opinion.*

