IYNT 2020

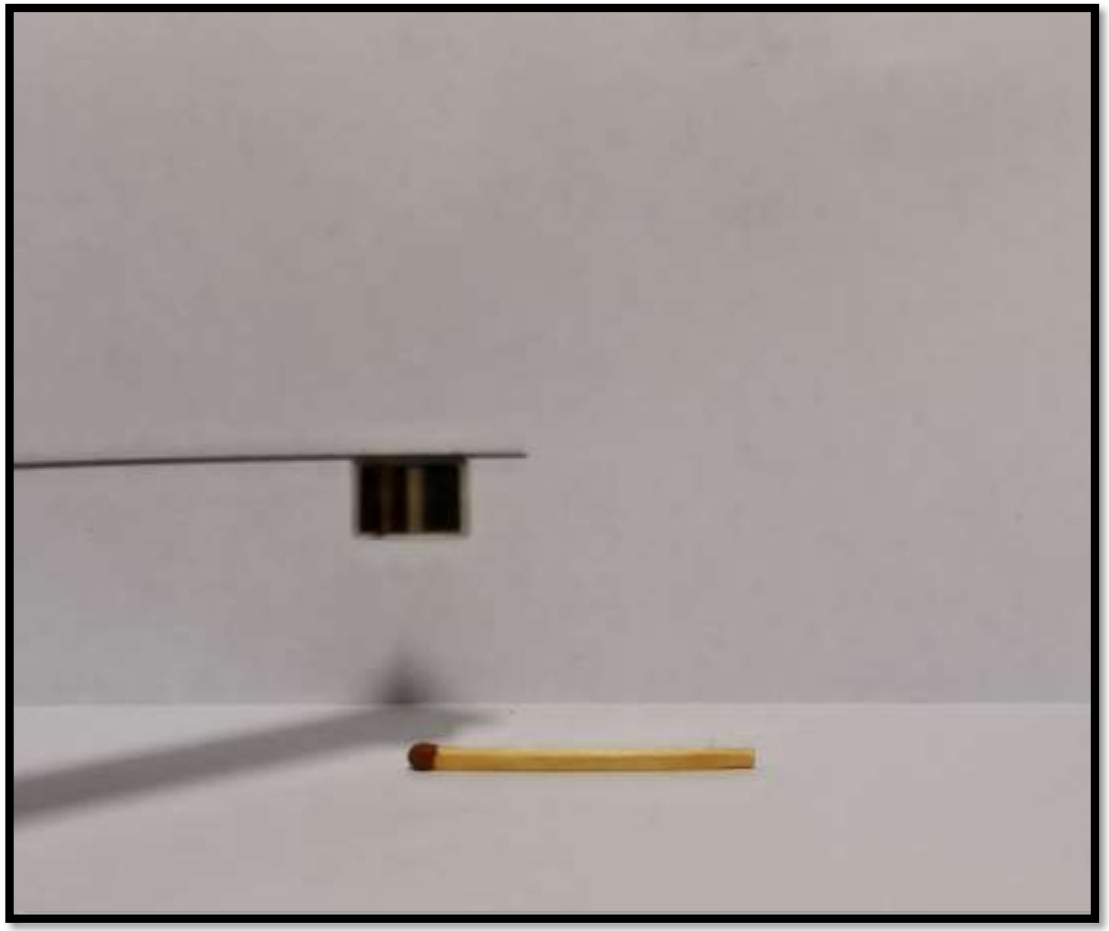
SAINT PETERSBURG

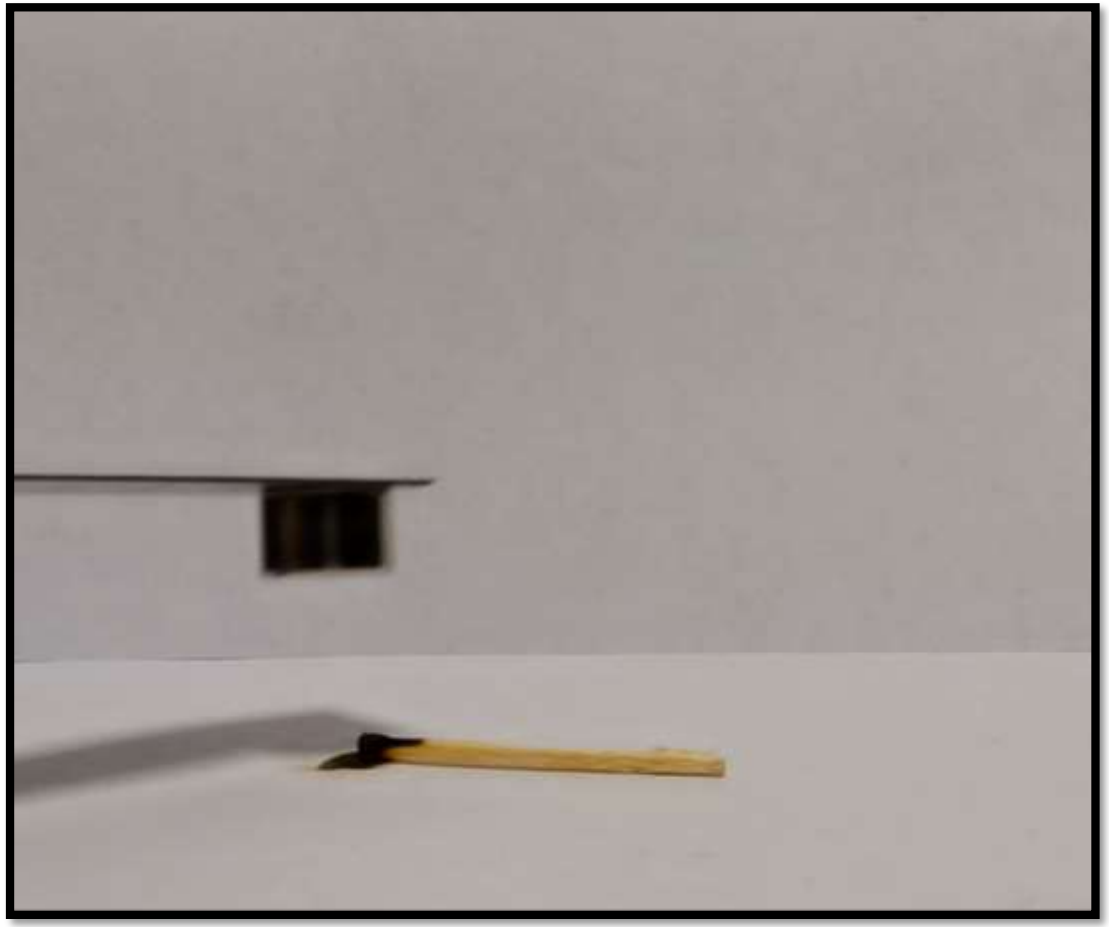
8. Magnet and matchstick

Russia – Element

Alina Nedikova

Task





A matchstick is not attracted to a magnet, however the head of a burned matchstick is attracted by a strong magnet. Investigate the reasons and the role of relevant parameters.

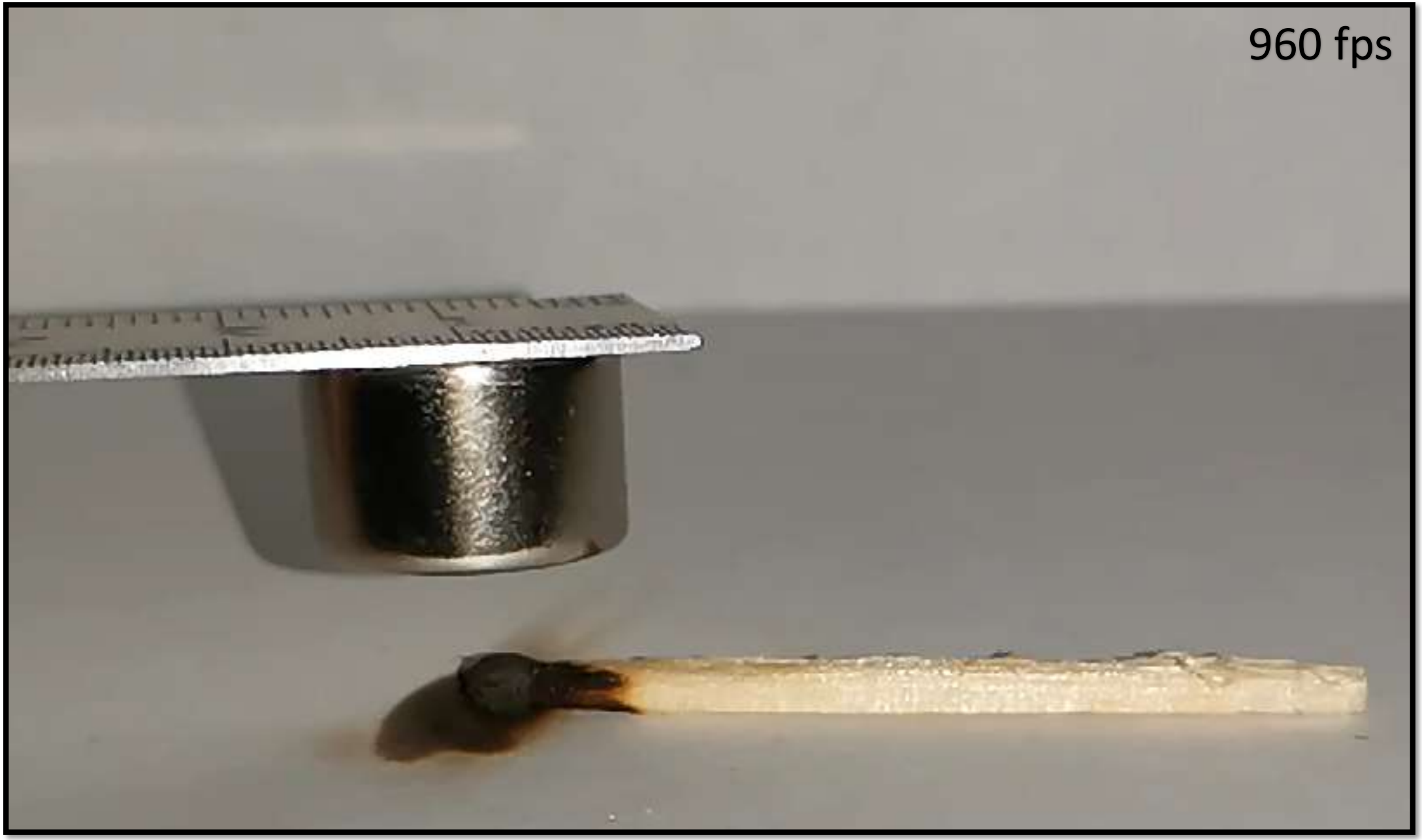
Hypothesis:

If after burning the match head there is a noticeable interaction with the magnet, the chemical reaction results in substances interacting with the magnet.

The aim of research:

to study the causes of the phenomenon of attraction of the burned match head.

Observation of the phenomenon



Magnetic properties

Weakly magnetic

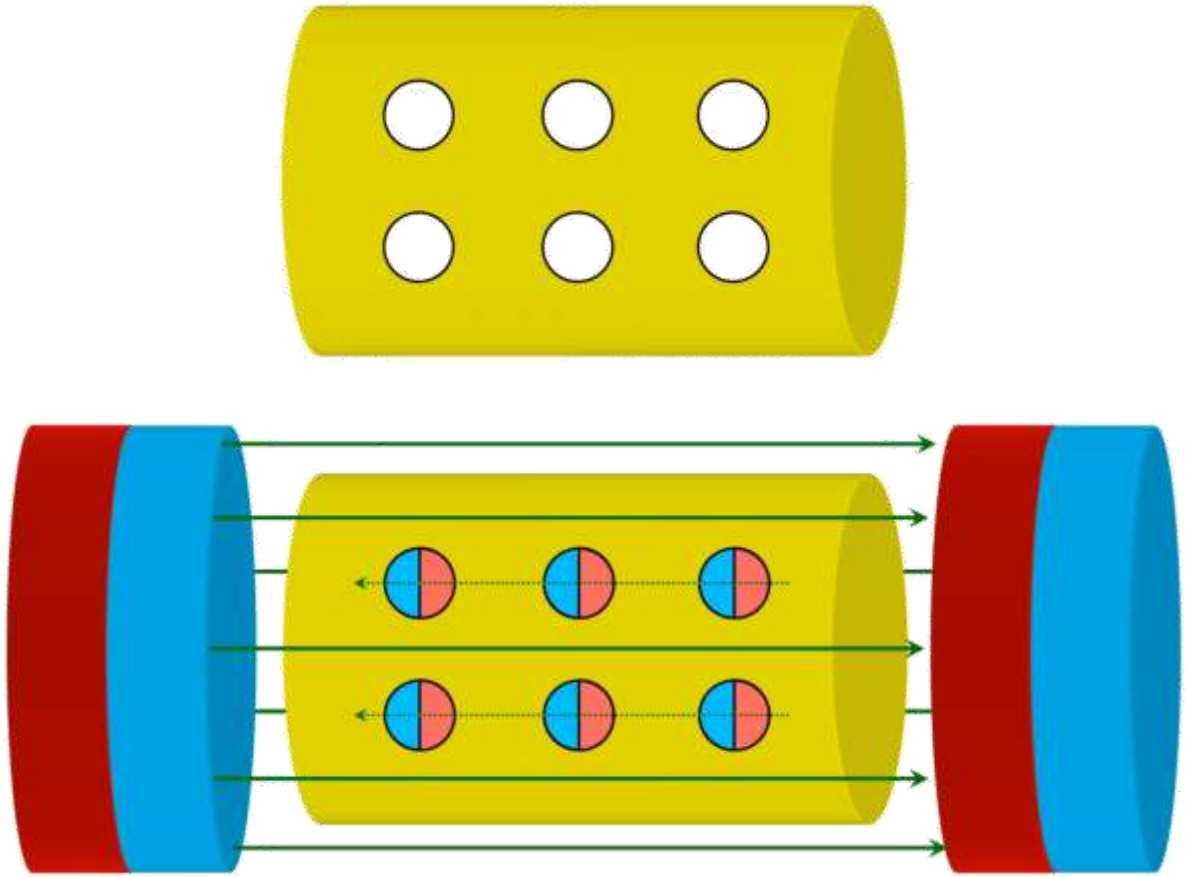
Strong magnetic

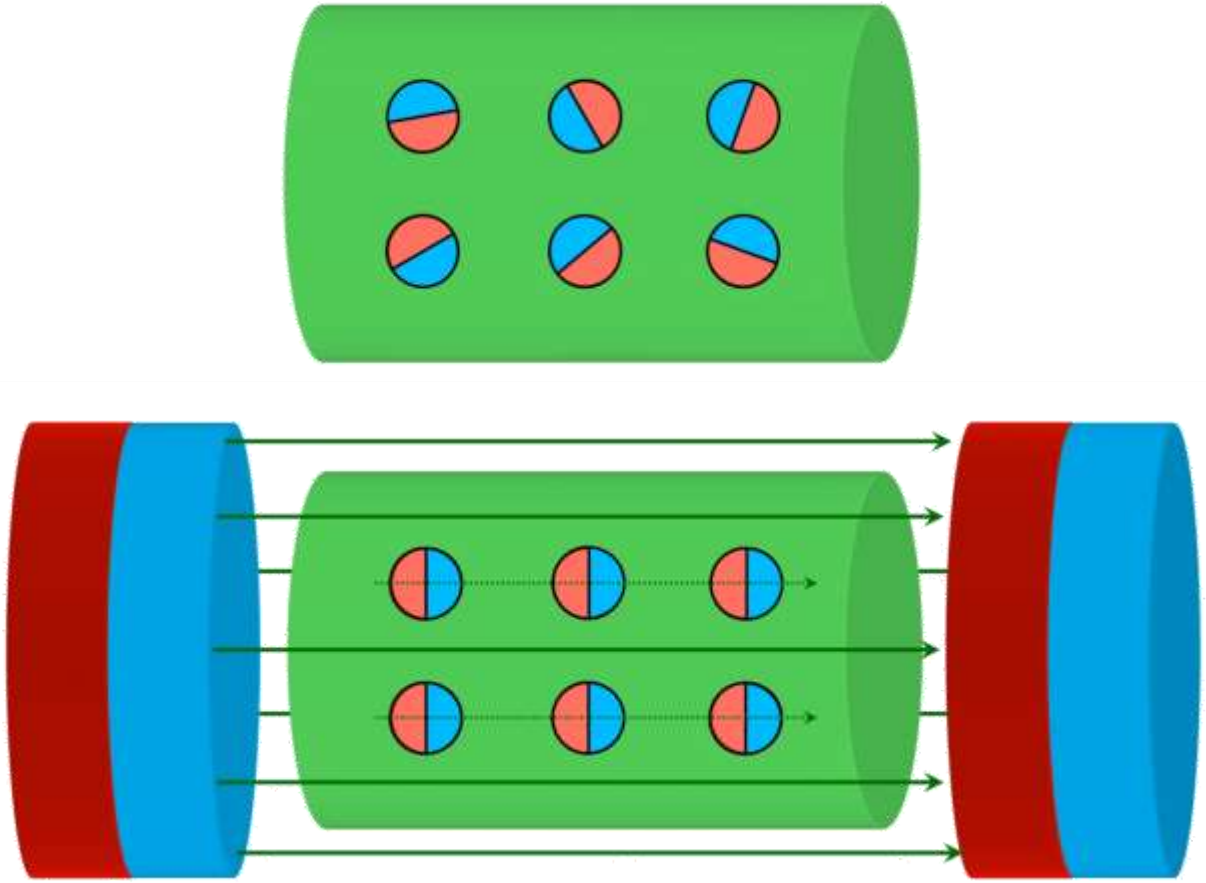
Diamagnetics

Paramagnetics

Ferromagnets

Diamagnetics & paramagnetics



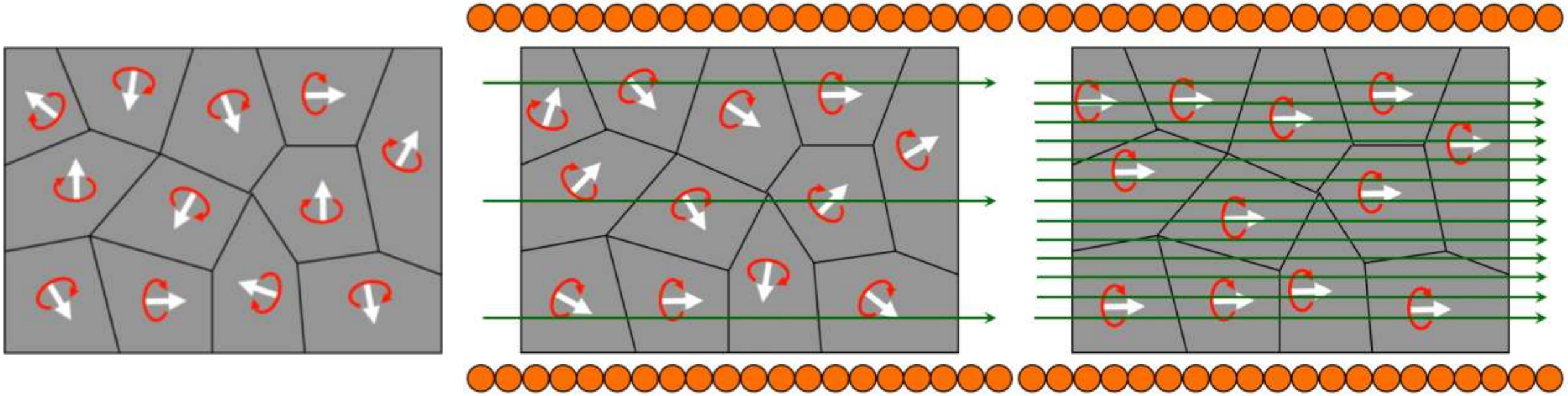


Diamagnetic molecules themselves don't possess magnetic properties, and when placed in an external magnetic field, elementary currents are induced in them, weakening this field.

Paramagnetic molecules are themselves tiny magnets. Due to the thermal motion, they are oriented randomly, so that the whole body is not magnetized. In an external magnetic field, the molecules rotate in the direction of the field, the body is magnetized and thereby enhances the external field.

https://www.youtube.com/user/getaclassrus

Ferromagnets

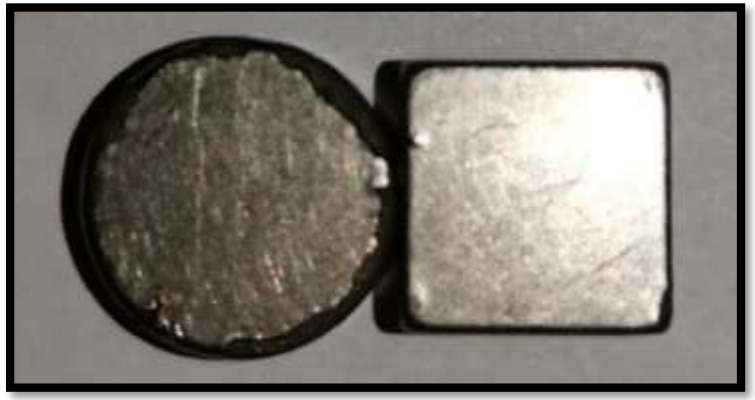


Ferromagnetics consists of small domains, which are always magnetized even if there is no external field. However, without an external field, these domains are oriented chaotically, so that in general the sample does not show any magnetization. When an external magnetic field appears, the domains begin to be magnetized by the field and their elementary currents create their own magnetic field, which turns out to be tens of times larger than the original external field.

Magnet characteristics

Material grade	Residual magnetic induction **Br**		Coercive force **Hc**		Maximum energy product **(BH) max.**		Working temperature **t**	Geometric dimensions d*h
	Tl	kG	kA/m	kOe	MGOe	Kj/m3	C	mm*mm
N42	1,30-1,33	13,0-13,3	955	12	42	334	80	15*10; 5*2
N35H	1,15-1,17	11,5-11,7	1355	17	35	279	120	12*3; 10*10*4

The properties of the magnet are determined by the characteristics of the demagnetizing section of the magnetic hysteresis loop of the magnet material: the higher **the residual induction Br** and **the coercive force Hc**, the higher the magnetization and stability of the magnet.



$Nd_2Fe_{14}B$

ГОСТ 1820-2001	dimensions, mm:
Match length	41,5
Match thickness	2,0
Match head length	≥2,5

Weight of one match $m \approx 0{,}097 \pm 0{,}0005\ g$

The exact composition of the match head is not specified in ГОСТ 1820-2001

Match head composition		
Berthollet's salt	$KClO_3$	46.5 %
Ground glass	SiO_2	17.2 %
Red lead	Pb_3O_4	15.3 %
Bone glue	-	11.5 %
Sulfur		4.2 %
White zinc	ZnO	3.8 %
Potassium dichromate	$K_2Cr_2O_7$	1.5 %

Berthollet's salt	$KClO_3$	53,03 %
Potassium dichromate	$K_2Cr_2O_7$	1,32 %
Pyrolusite	MnO_2	1,50 %
Sulfur	S	5,23 %
White zinc	ZnO	4,17 %
Ground glass	SiO_2	16,70 %
Iron red lead	Fe_2O_3	6,38 %
Mezdrovy glue	–	5,38 %
Bone glue	–	6,02 %
Gummitragant	–	0,27 %

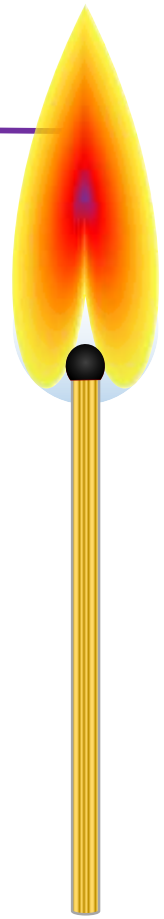
There is no evidence in papers and patents

Bystrov. Technology of matchstick production. M.: Goslesbumizdat, 1961, p.60

Match

When the head of a match is ignited, the following oxidation and reduction reactions occur:

800-900°C



$$2KClO_3 + 3S \longrightarrow 2KCl + 3SO_2 + Q$$

$$2KClO_3 \longrightarrow 2KCl + 3O_2$$

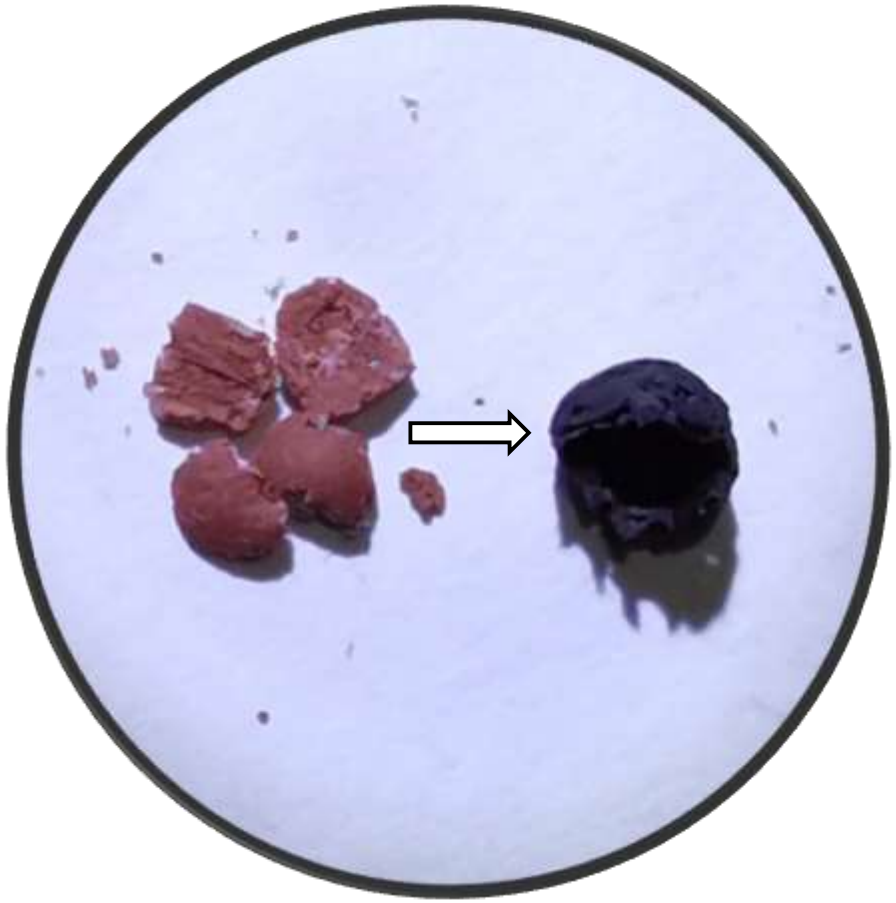
$$S + O2 \longrightarrow SO_2$$

$$(C_6H_{10}O_5) + 6O_2 \longrightarrow 6CO_2 + 5H_2O$$

$$K_2Cr_2O_7 + S \longrightarrow Cr_2O_3 + K_2SO_4$$

Other reactions also occur, but they are rather difficult to predict

Match head composition



In the article, an elementary analysis was carried out, as a result of which, among several types of matches, the presence of **Fe** was found in a match, which was attracted after combustion, unlike the others. And it was also experimentally determined that before the combustion of the match, $\mathbf{Fe_2O_3}$ was present, and after that $\mathbf{Fe_3O_4}$ ($\mathbf{Fe_2O_3}$***FeO**) appeared.

Magnetite $\mathbf{Fe_3O_4}$ is a ferrimagnetic mineral easily attracted by a magnet, and its absence in an unburned match explains the weak attraction

Magnetic safety matches - J Lindén

Most likely, a reduction reaction occurs similar to the following:

$$6Fe_2O_3 + S \longrightarrow 4Fe_3O_4 + SO_2$$

The sulfur content in the head of a match is high enough for the reaction to proceed, however, it is necessary to find the Gibbs free energy for the temperatures in order to finally make sure that the reaction will proceed. If it is less than zero, the reaction proceeds

$$\Delta H = \sum \Delta H_{products} - \sum \Delta H_{initial} = 164.4\, kJ/mol;$$

$$\Delta S = \sum \Delta S_{products} - \sum \Delta S_{initial} = 261.72\, J/(K \cdot mol);$$

$$\Delta G_T = \Delta H - T\Delta S = 164.4 - T\frac{261.72}{1000} kJ/mol < 0;$$

$$T > \frac{164.4}{261.72} 1000 \approx 628\, K = 355^\circ C$$

Consequently, at temperatures above 355 ° C, the reaction proceeds.
Our temperatures are around 800-900 ° C

Consider all substances before and after the reaction that could have magnetic properties

$K_2Cr_2O_7$	Not ferromagnetic
MnO_2	Paramagnetic
ZnO	Not ferromagnetic
Cr_2O_3	Not ferromagnet
Fe_2O_3	Weak ferromagnet
Fe_3O_4	Ferromagnetic

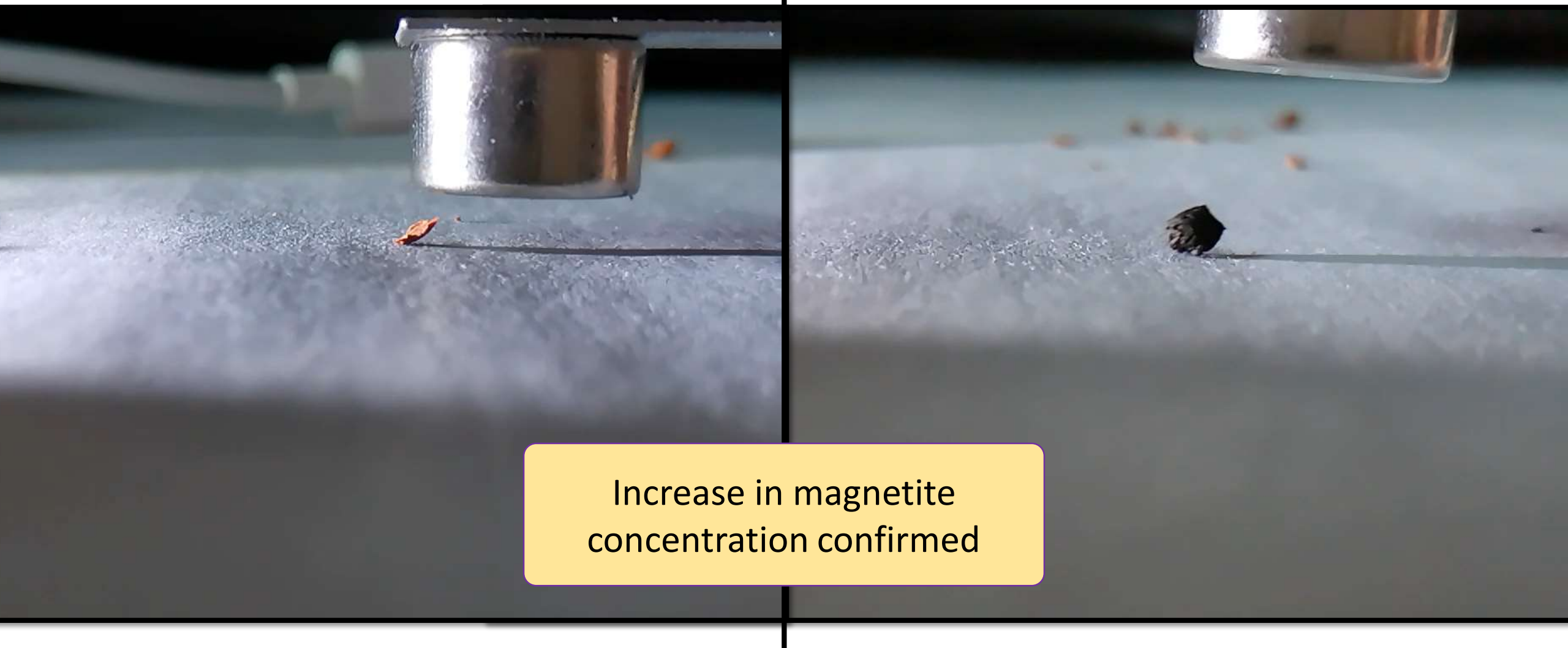
You can see that only Fe_3O_4 has good magnetic properties, which explains the best attraction of a burnt match to a magnet.

However, if you use a strong enough magnet to attract (or reduce the weight of the match), you can also attract an unburned match due to the presence of Fe_2O_3, which has magnetic properties.
This is confirmed by the experiment on the next slide.

Match head

before combustion

after combustion



Increase in magnetite concentration confirmed

Permanent magnet magnetic field

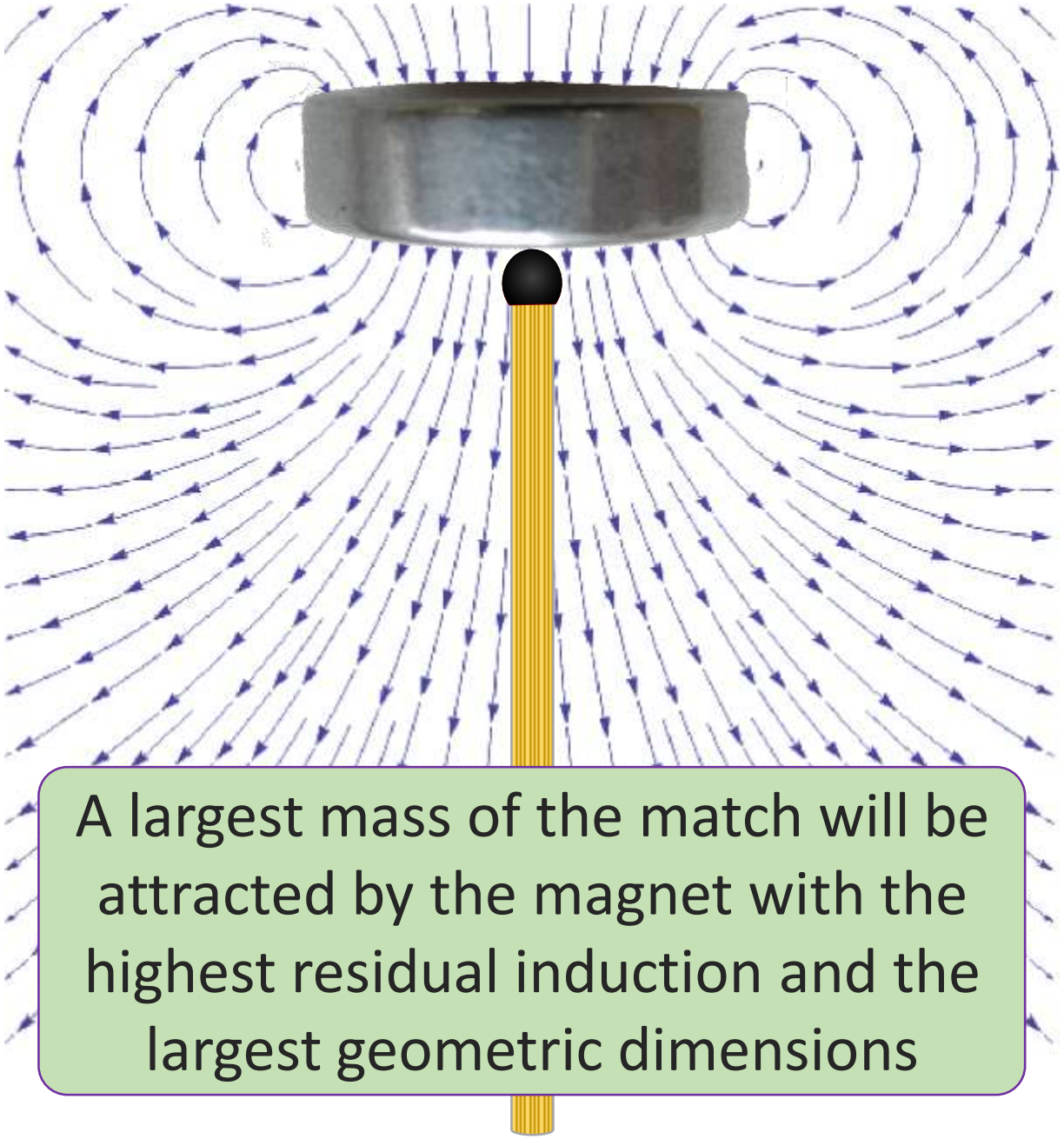
$$\Phi = (\mathbf{B} \cdot \mathbf{S}) = B \cdot S \cdot \cos\alpha$$

B – vector of magnetic induction

S – permeable surface area

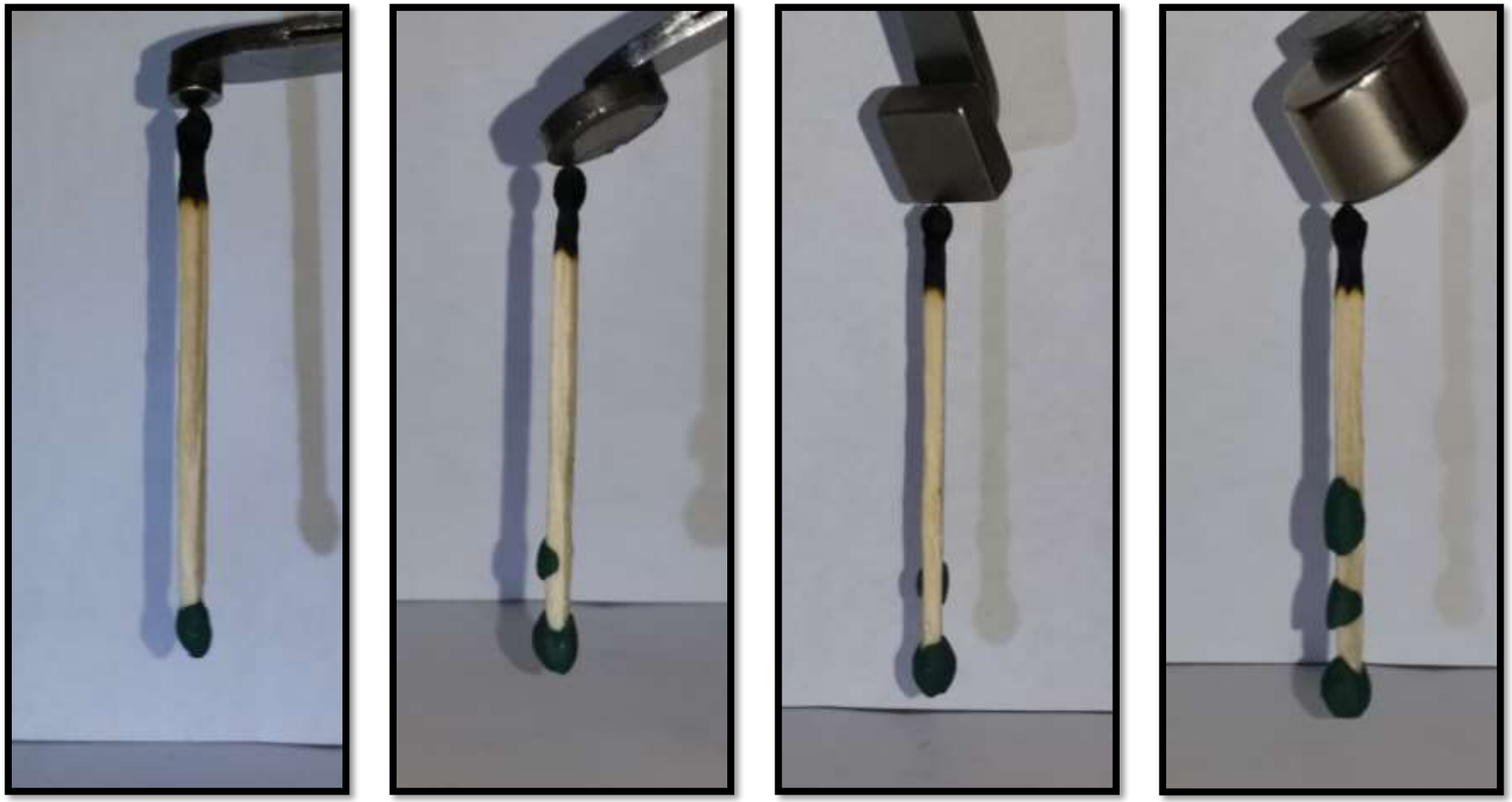
The maximum weight that the magnet can hold by pulling the head will depend on:

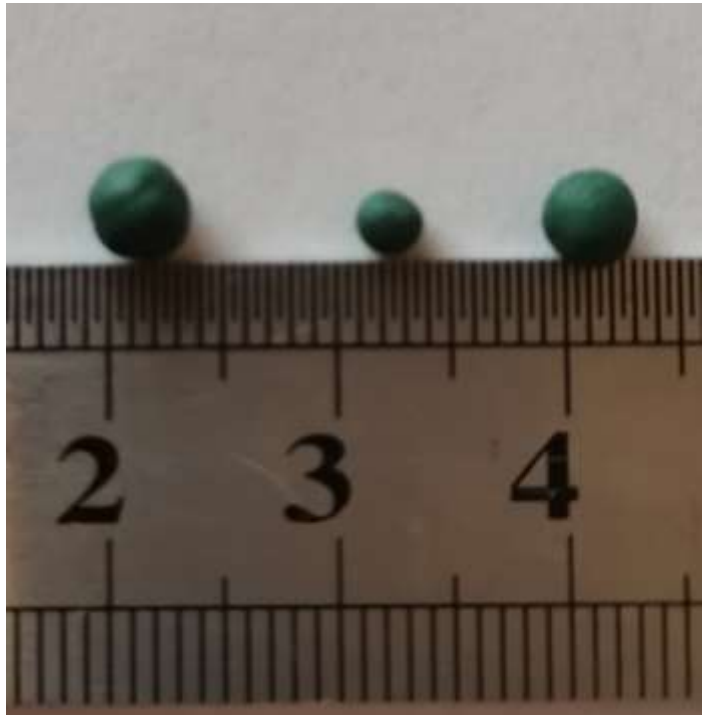
- the value of the magnetic induction vector determined by **the residual induction**
- Match head surface areas
- The angle between the vector of magnetic induction and the normal to the surface of the match head, determined by **the geometric dimensions** of the magnet



A largest mass of the match will be attracted by the magnet with the highest residual induction and the largest geometric dimensions

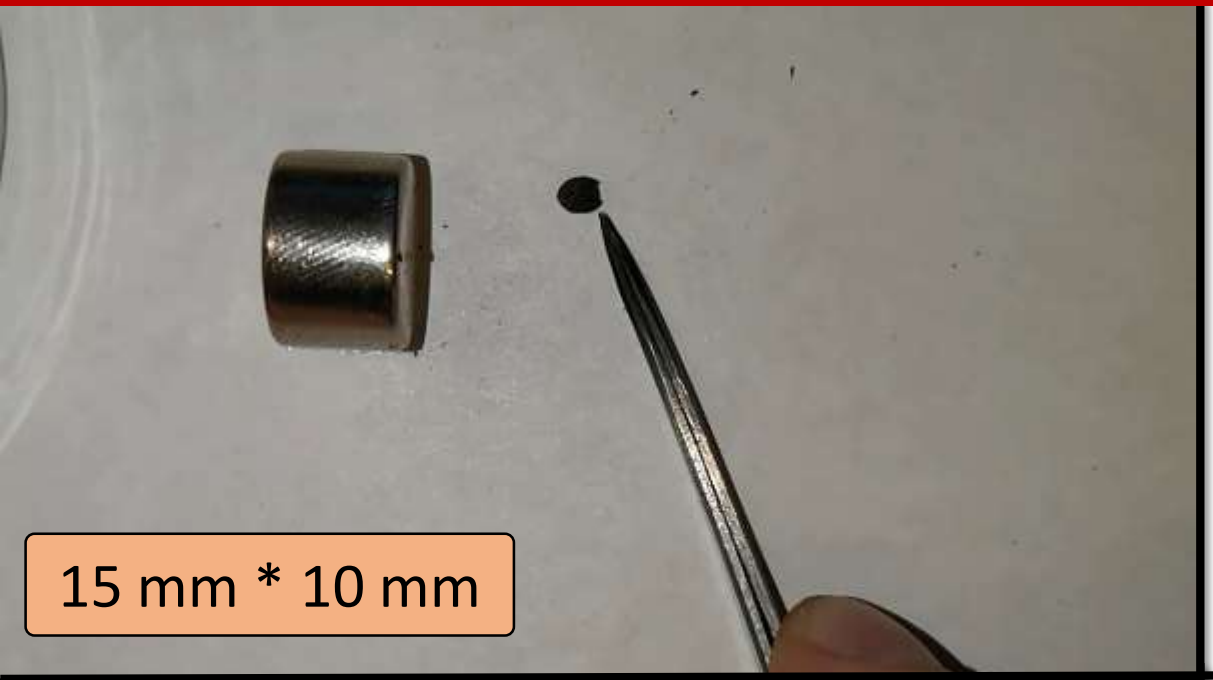
Permanent magnet magnetic field

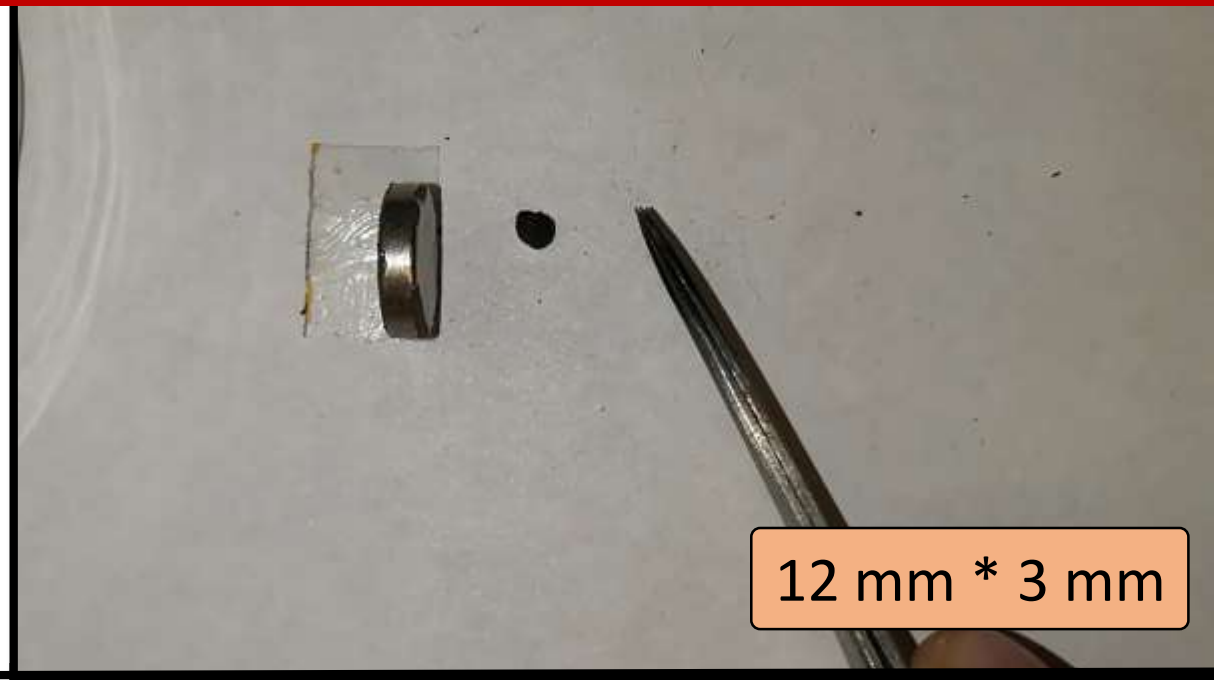


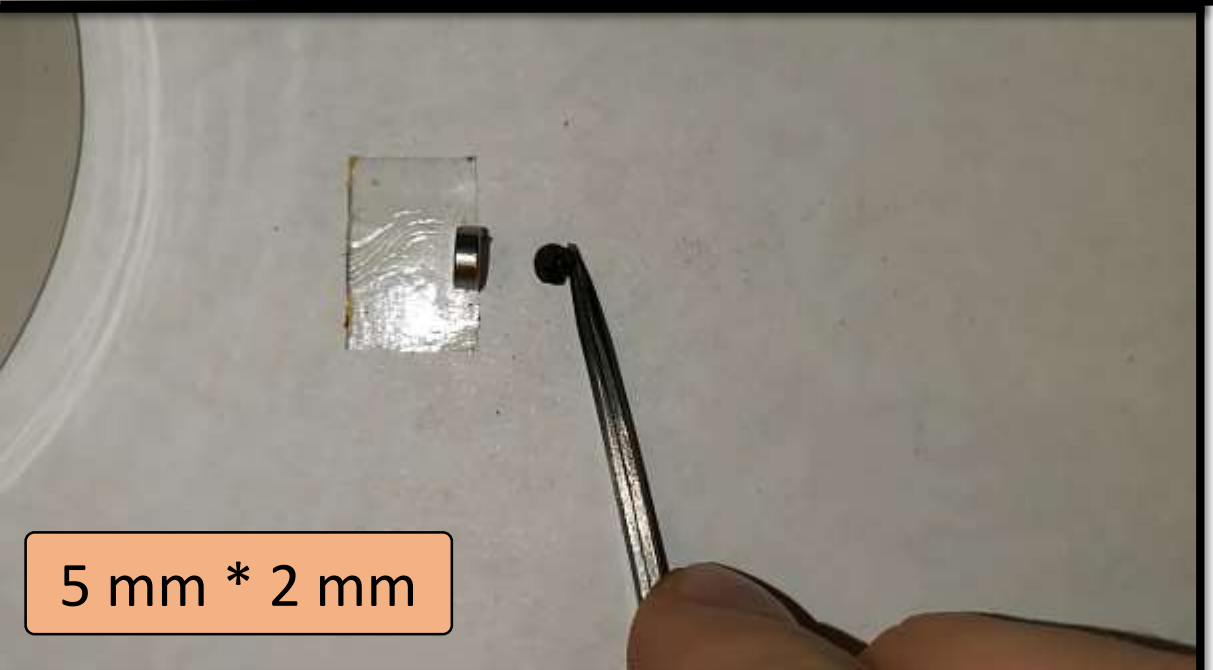


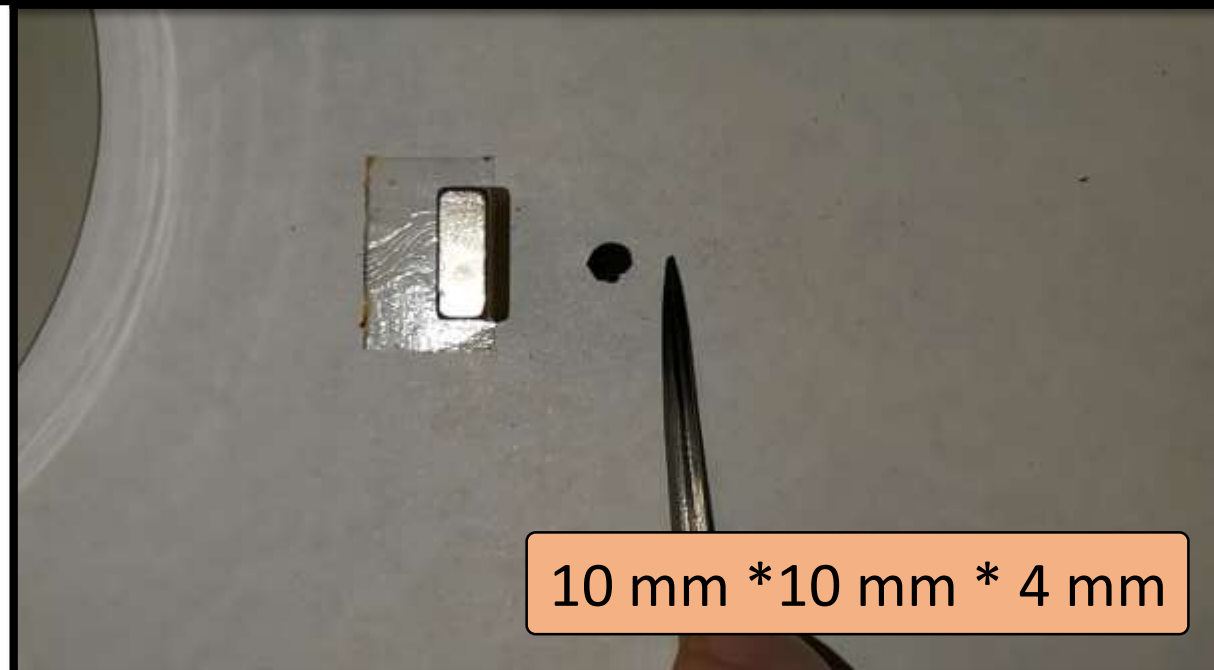
Maximum holding weight by pulling the head of a match			
~0,19 g	~0,22 g	~0,24 g	~0,31 g

Attraction distance

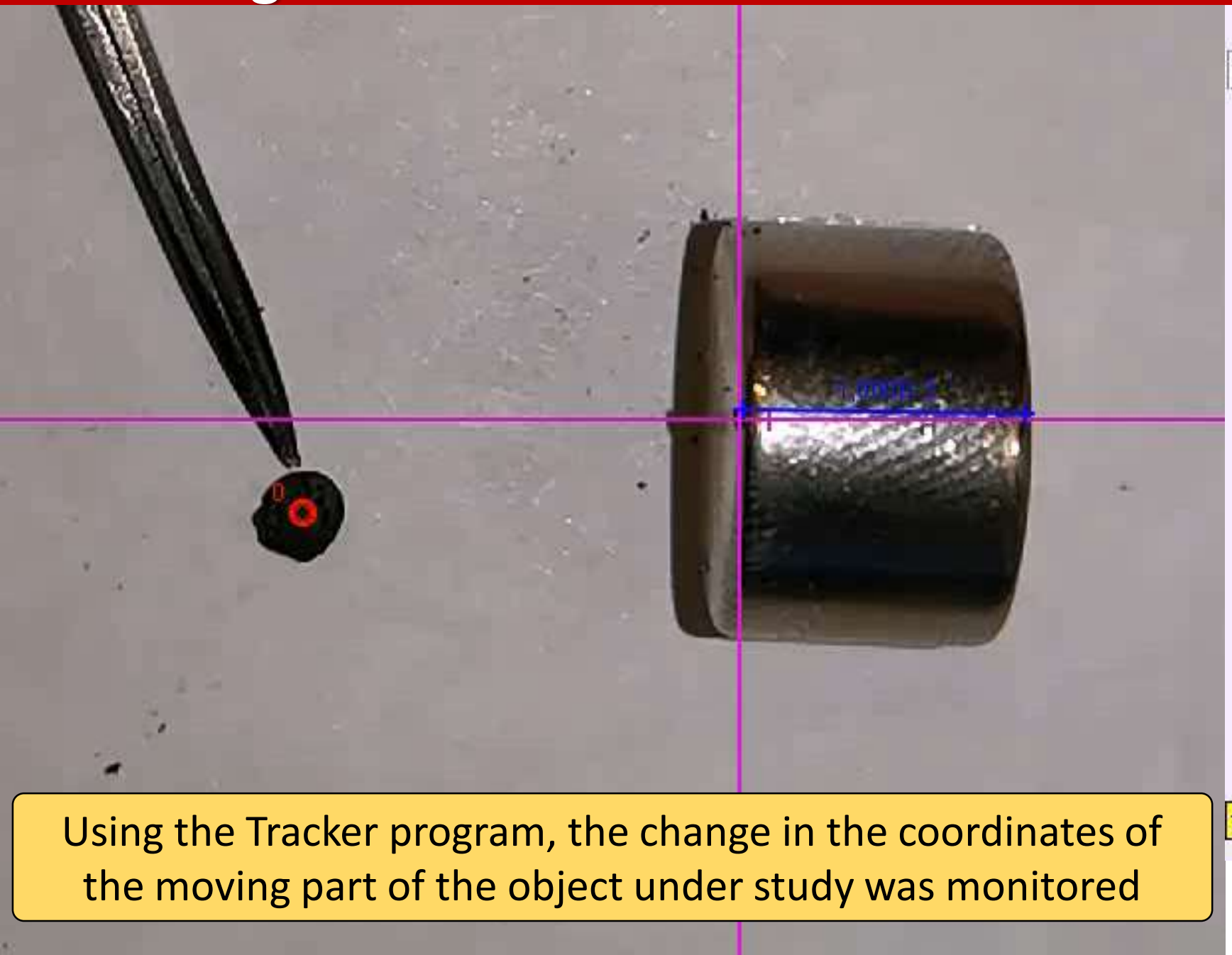


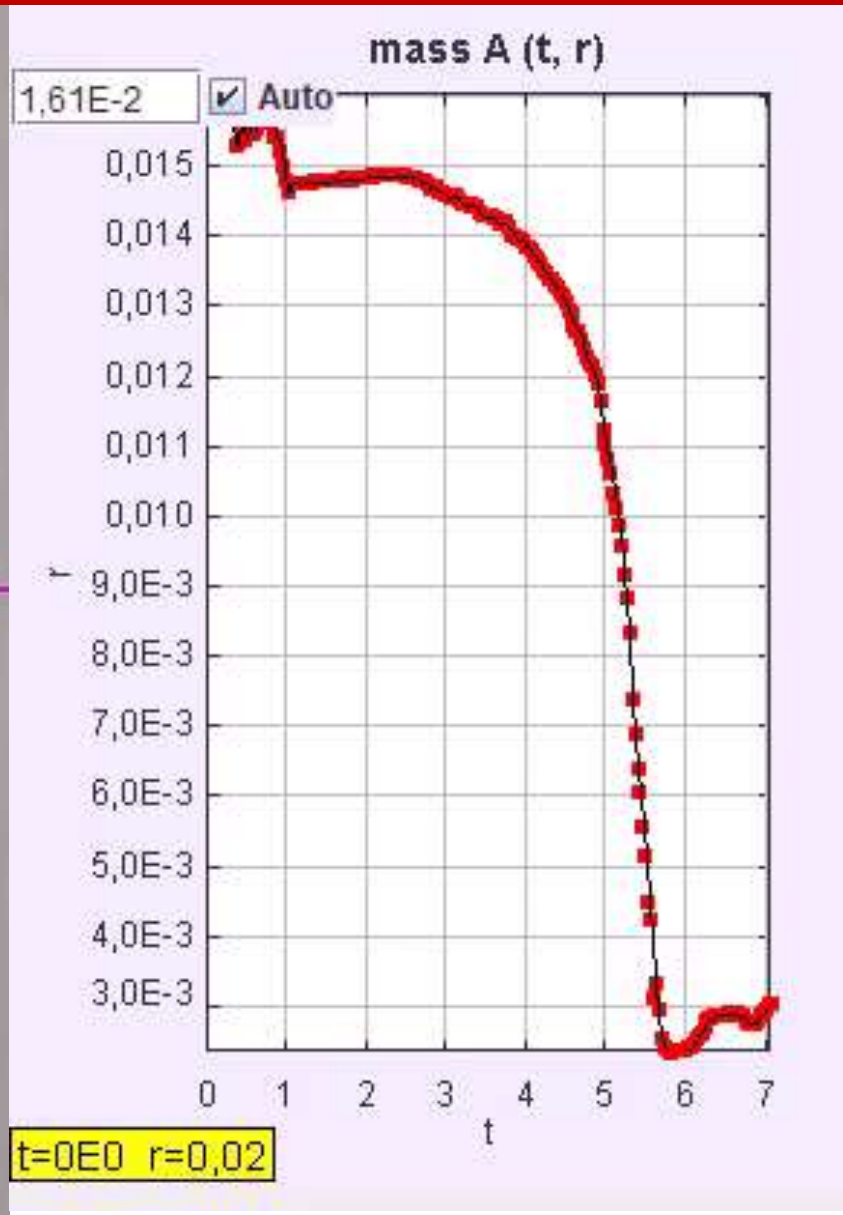






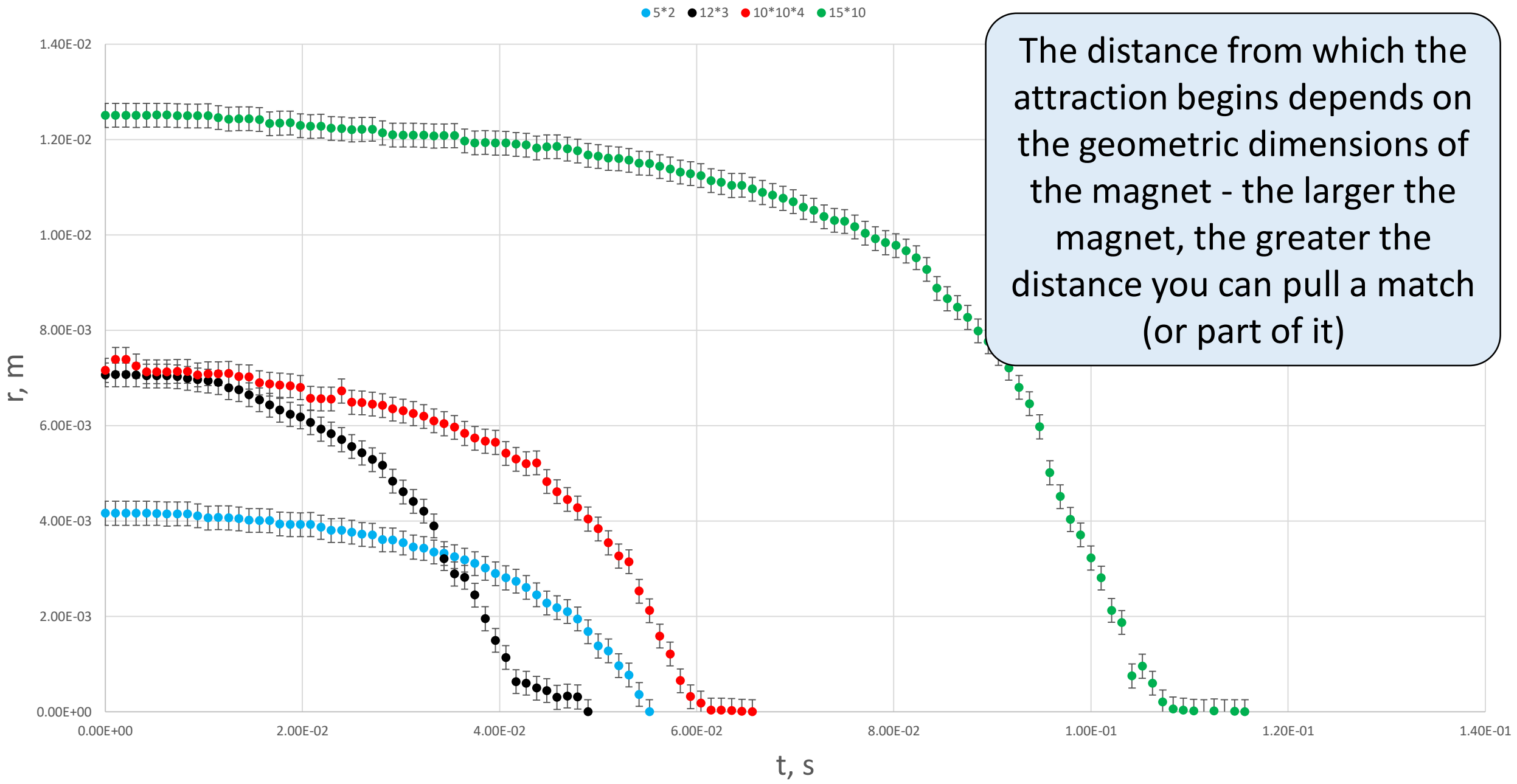
Plotting





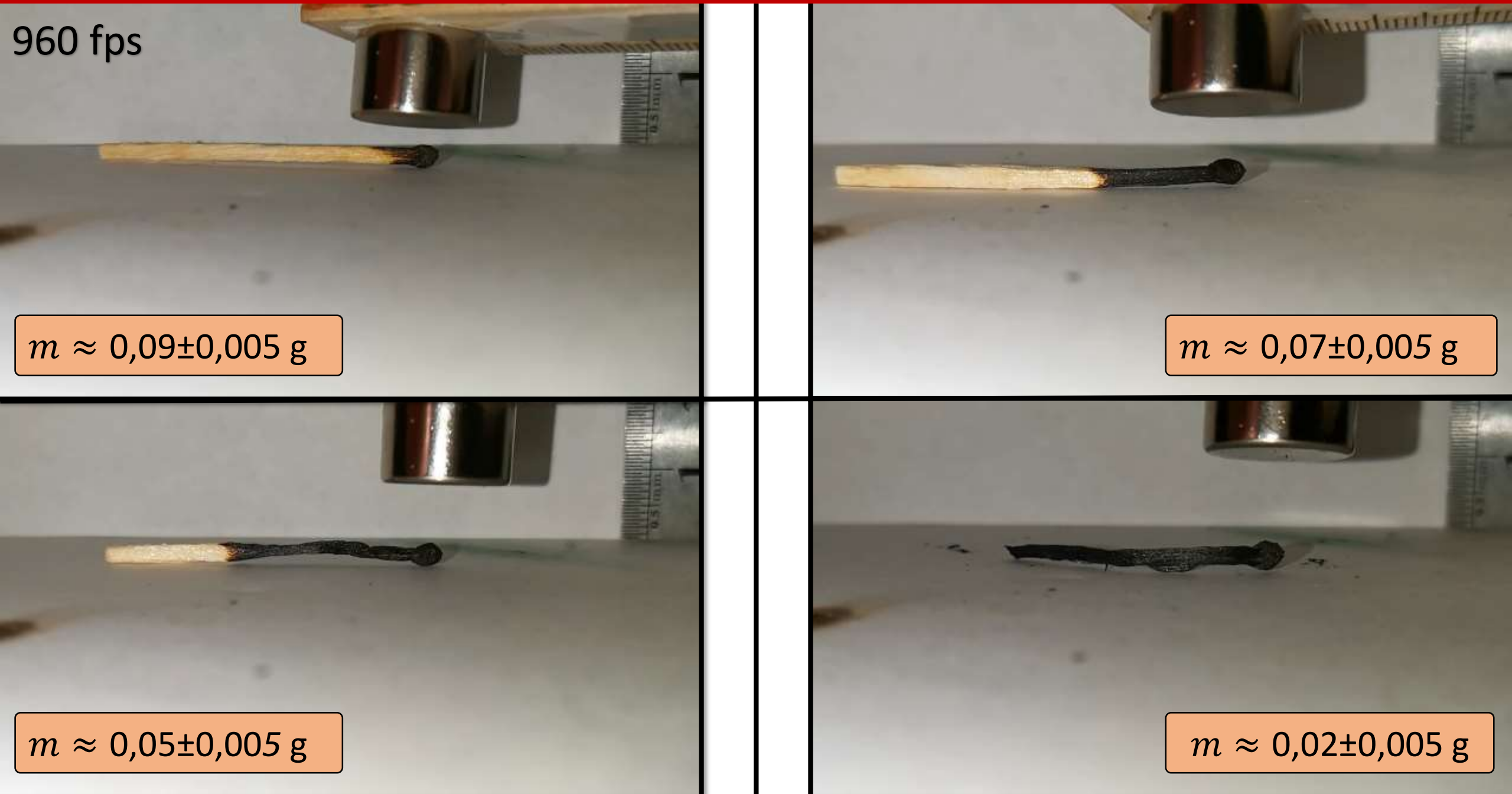
Using the Tracker program, the change in the coordinates of the moving part of the object under study was monitored

Attraction distance

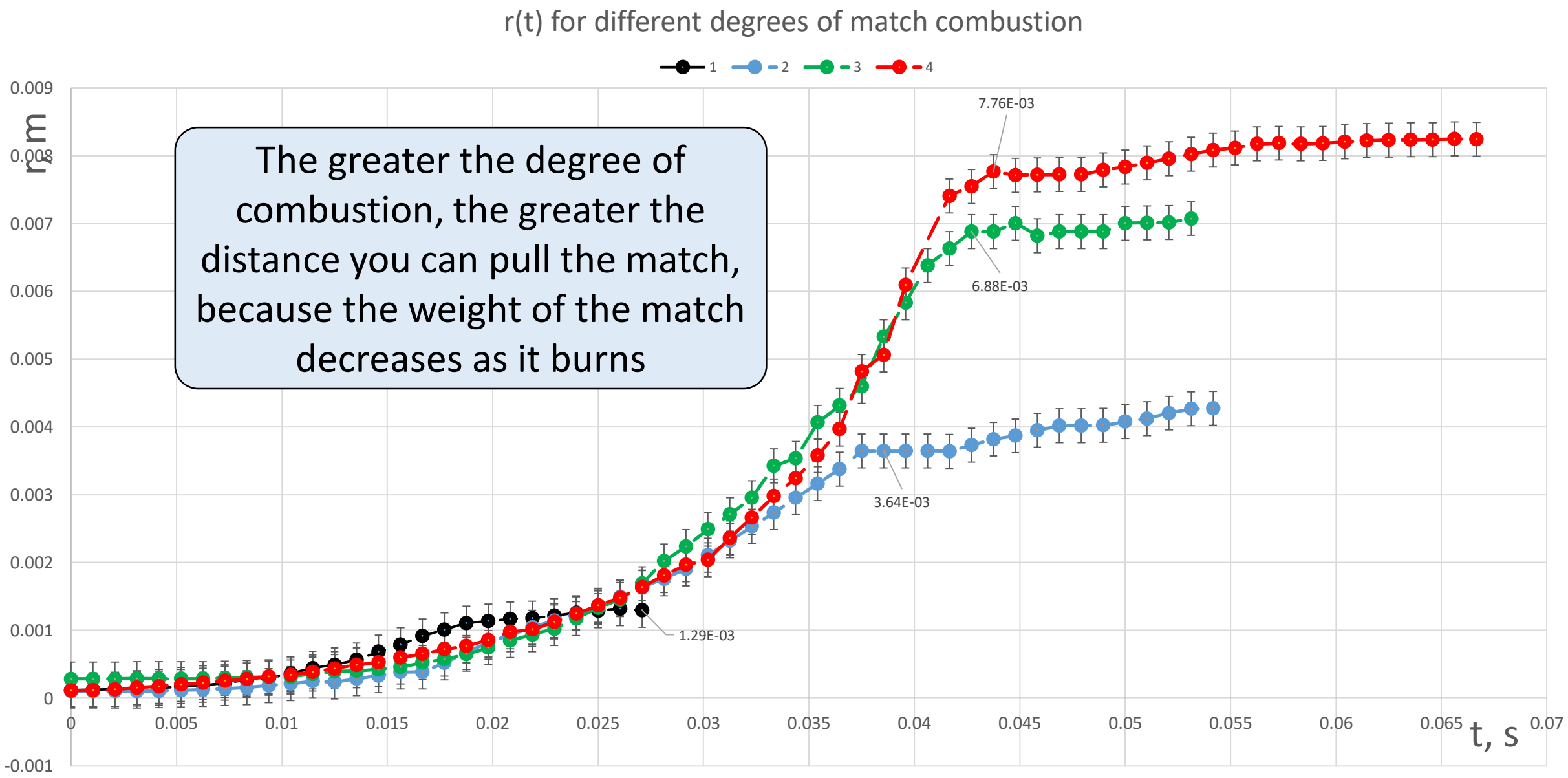


The distance from which the attraction begins depends on the geometric dimensions of the magnet - the larger the magnet, the greater the distance you can pull a match (or part of it)

Influence of the degree of combustion on the distance of attraction

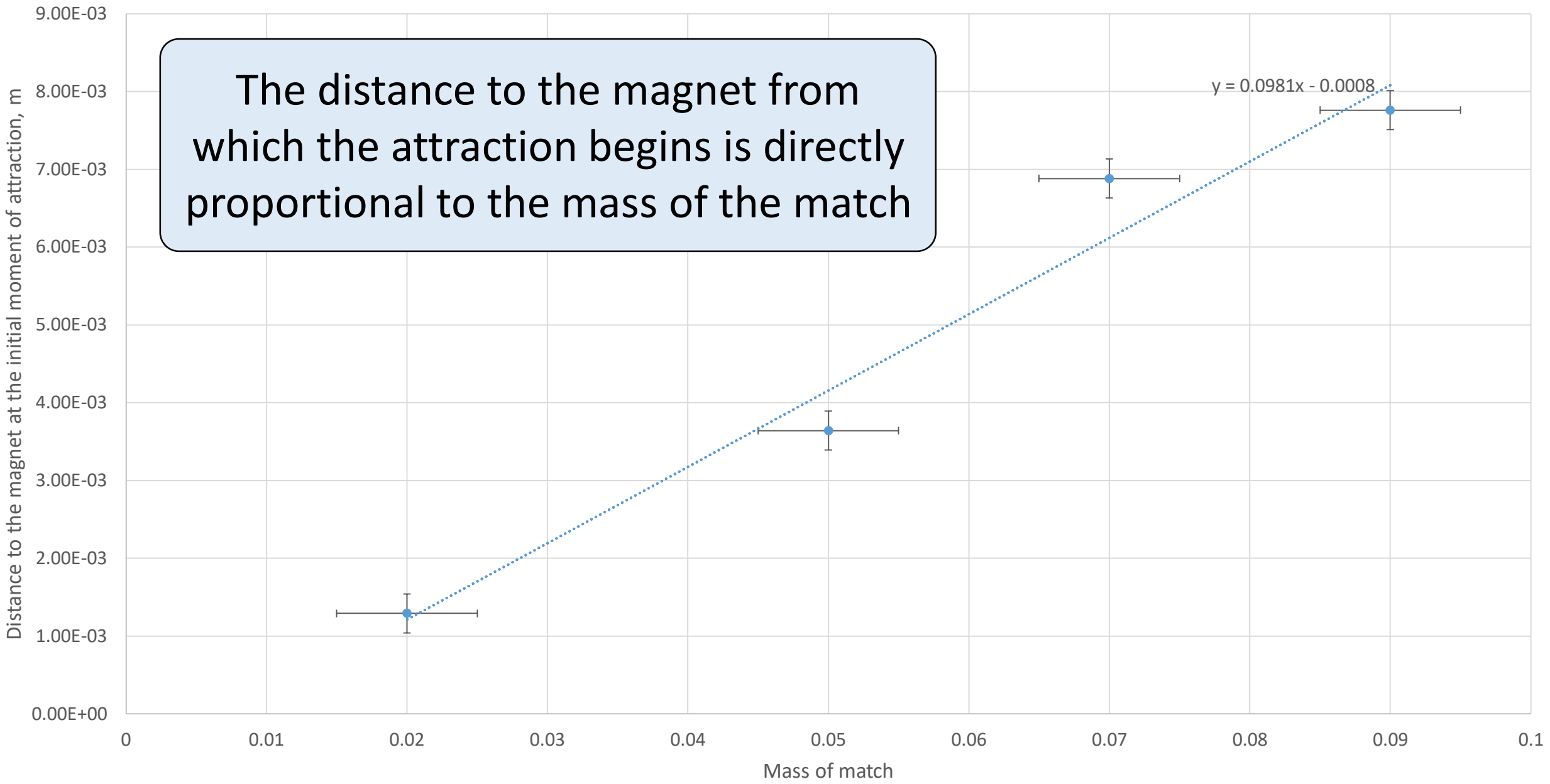


Influence of the degree of combustion on the distance of attraction



The greater the degree of combustion, the greater the distance you can pull the match, because the weight of the match decreases as it burns

Influence of the degree of combustion on the distance of attraction



The distance to the magnet from which the attraction begins is directly proportional to the mass of the match

Conclusions

Investigate the reasons why the head of a burned matchstick is attracted by a strong magnet

A burnt match is attracted to the magnet due to the increase in the content of magnetite Fe_3O_4 during the reduction reaction, which has better magnetic properties than the original substances

Investigate the role of relevant parameters in the attraction of a burned matchstick

Than the higher the degree of combustion that the more distance you can pull a match, because the weight of the match decreases as it burns

The distance from which the attraction begins depends on the geometric dimensions of the magnet - the larger the magnet, the greater the distance you can pull a match (or part of it)

Than the larger the geometrical dimensions and the residual magnetic induction of the magnet that the more mass the magnet can hold