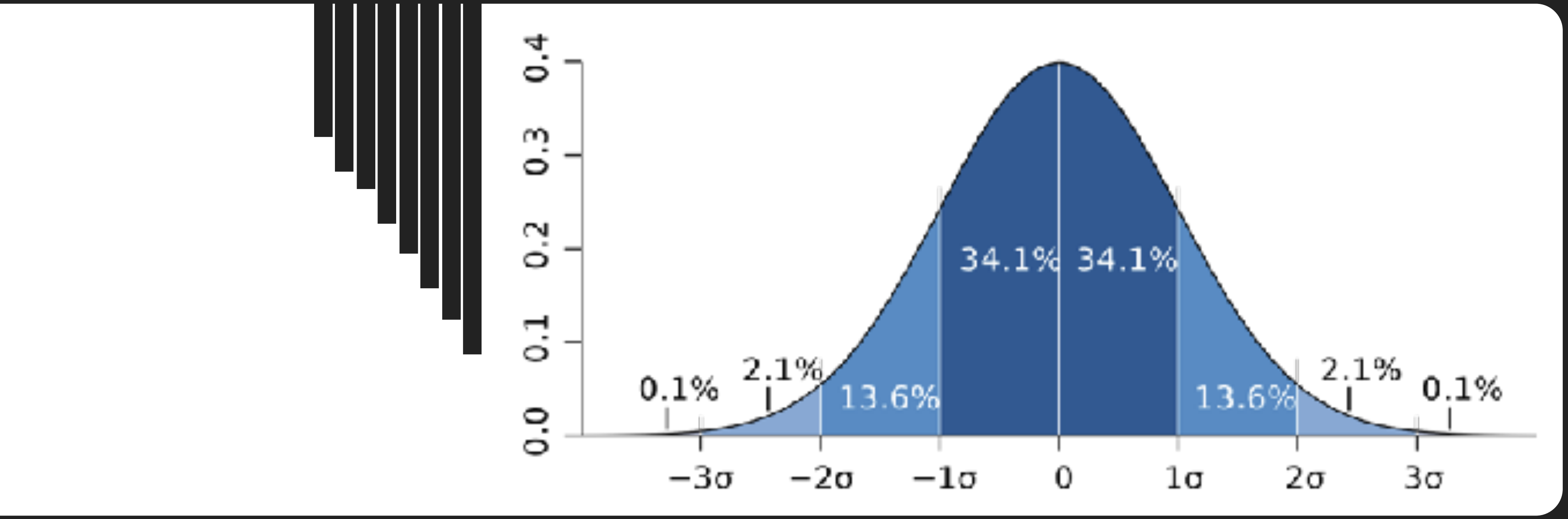

R. BRICEÑO, T. ROGERS

MAGNETS AND SYMMETRIES

ADMIN STUFF

Need links, just email python4physics@odu.edu

Move to...

Python 4 Physics 5:19 PM PP

Automatic reply:

To: Briceno, Raul A.

Thanks for your interest in Python4Physics.

Please visit our webpage at https://sites.google.com/view/odu-nuc-th/service/p4p-2020. In addition to providing links to our Dropbox folder, you will see our "Frequently Asked Questions" section. There we answer the many questions we have been receiving.

Slack chat with faculty and TAs: https://join.slack.com/t/python4physics/shared_invite/zt-ffgssu43-4x9_bCCLmGt8dou~Xwzycw. Note, to use Slack you must be at least 16yrs old [see https://slack.com/terms-of-service].

Livestreams link: https://vs.prod.odu.edu/bin/reyes_system/

Recordings link: https://odu.edu/reyes/recordings
Reyes - Python4Physics archive: https://vs.prod.odu.edu/bin/reyes_system/archives/6_python4Physics.php
Reyes - Python4Physics breakout sessions archive: https://vs.prod.odu.edu/bin/reyes_system/archives/6_python4Physics_breakouts.php

Dropbox link: https://www.dropbox.com/sh/ur6mk8gzl22mq41/AACRe9R4Ulb-4bYAvJG2UI3aa?dl=0

Briceno, Raul A. 5:19 PM RB

(No Subject)

To: Python 4 Physics

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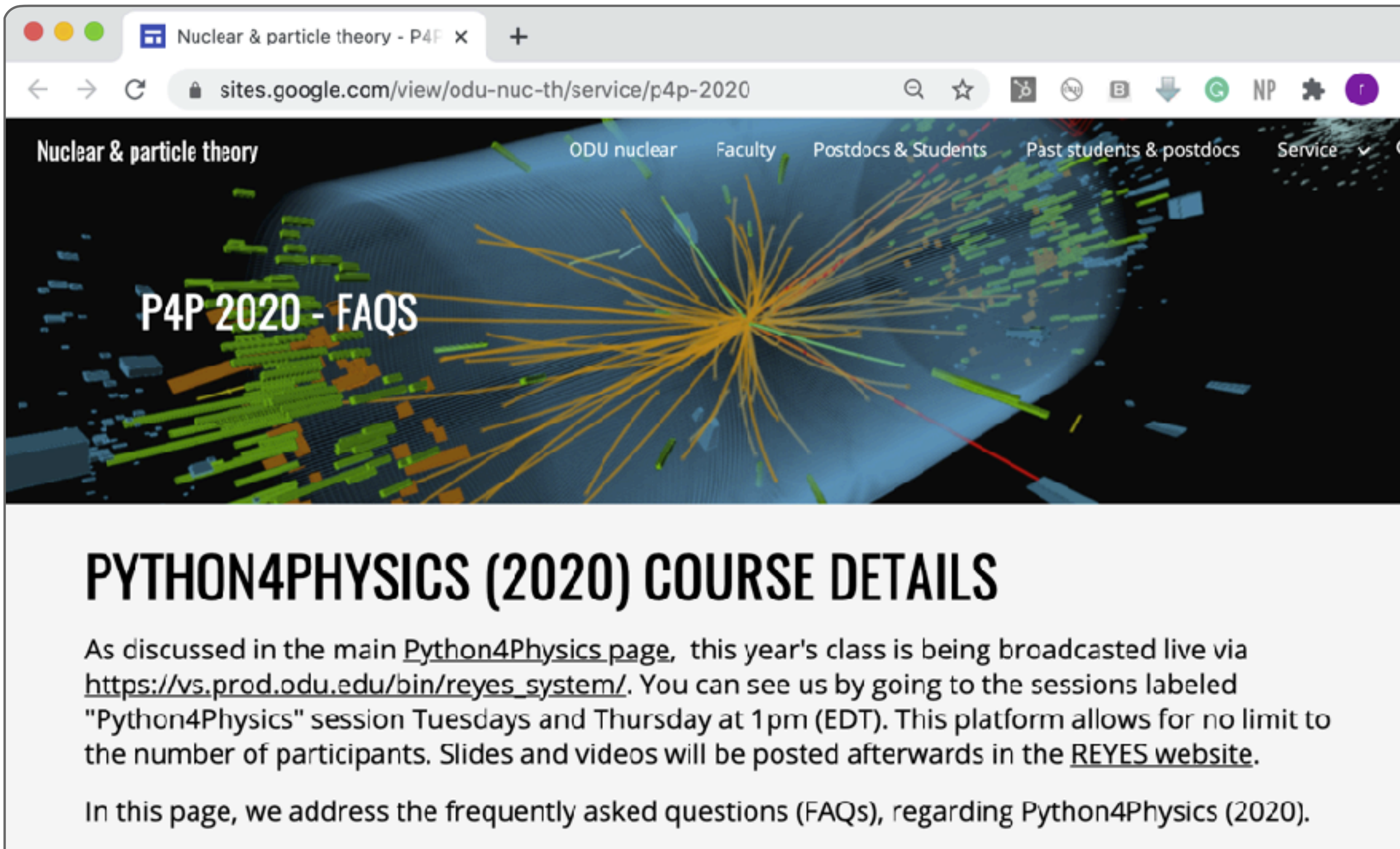

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Dropbox for students, email us! Subject: “Dropbox access”

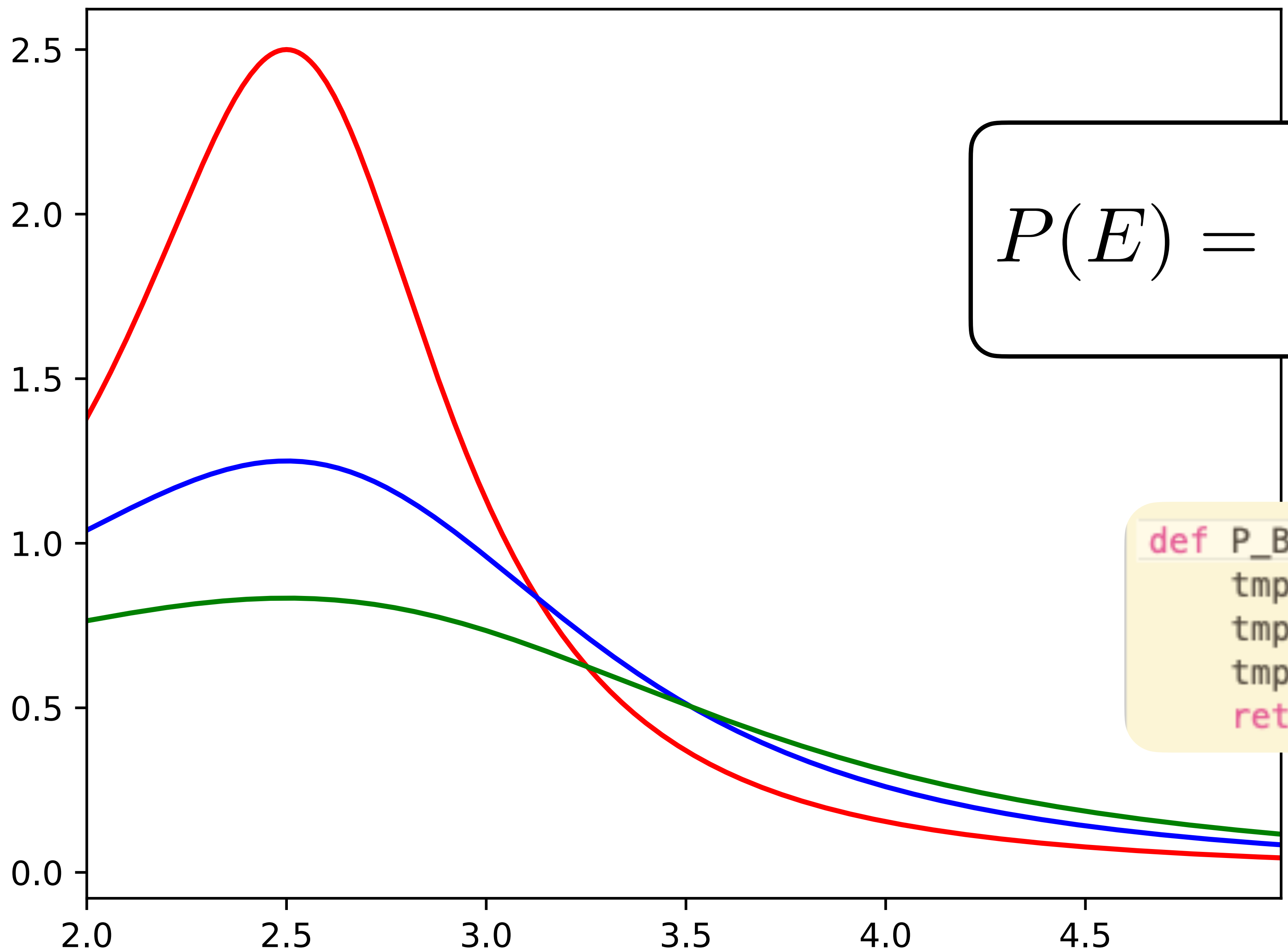
REVIEW

EXERCISE #1 - PLOTTING A BREIT-WIGNER

The three values of the decay width are $\Gamma = 1, 2, 3$.

Reproduce this plot, and figure out which color correspond to which value.

Hint: Develop some intuition. How does the distribution behave as a function of the width at its peak. Does it grow or decrease with the Γ?



$$P(E) = \frac{M^3\Gamma}{(E^2 - M^2)^2 + M^2\Gamma^2}$$

```
def P_BW(E):
    tmp1 = pow(pow(E,2)- pow(M,2) , 2)
    tmp2 =  pow(M*Gamma,2)
    tmp3 =  pow(M,3)*Gamma
    return tmp3 / ( tmp1 + tmp2 )
```

look inside my code 😎

PYTHON ROUTINES FOR MINIMIZATION

scipy has many different routines for optimization and root finding: https://docs.scipy.org/doc/scipy/reference/optimize.html

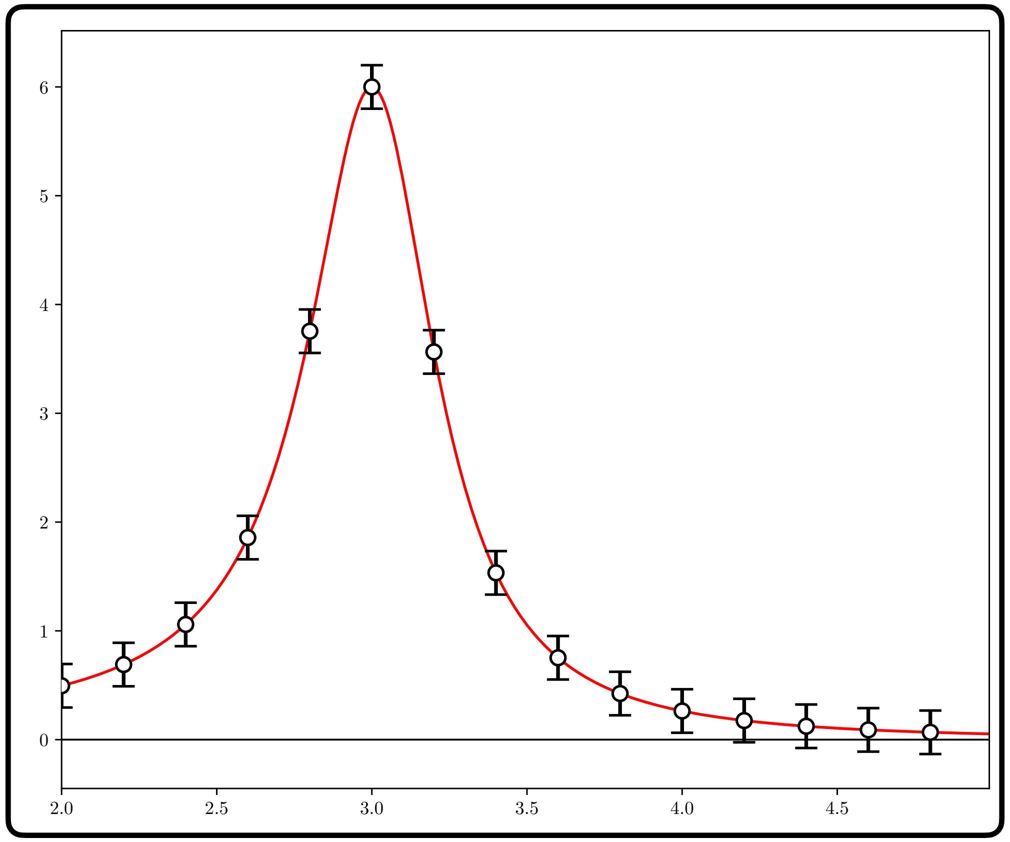
Here is a simple one I use}

```python
def chi2_BW(M_Gamma):
    M,Gamma = M_Gamma
    Pis = P_BW(M,Gamma,Xs)

    chi20 = np.sum(pow((Pis-Ys)/sigs,2))
    dof = len(sigs)-2.0
    return chi20

def find_min_chi2_BW():
    M_Gamma_guess = [2.,1.0]
    """
    https://docs.scipy.org/doc/scipy/reference/generated/scipy.optimize.minimize.html
    """
    from scipy import optimize
    M_Gamma = optimize.minimize(chi2_BW, M_Gamma_guess, method='nelder-mead')
    print("M_Gamma",M_Gamma)
    return M_Gamma.x
```

minimum coincides with $(M,\Gamma) = (3, 0.5)$

```
In [80]: import BW_plots
M_Gamma  final_simplex: (array([[2.99995863, 0.49998755],
       [2.9999788 , 0.50007577],
       [3.00004901, 0.49990999]]), array([2.17813848e-05, 3.02255241e-05, 5.72629601e-05]))
           fun: 2.1781384810732297e-05
       message: 'Optimization terminated successfully.'
          nfev: 103
           nit: 55
        status: 0
       success: True
             x: array([2.99995863, 0.49998755])
```

plotting the distribution using the fitted values…



EXERCISE #2 - WARM UP…FIT A CONSTANT

Load the data in **Dropbox:/P4P_2020/project# 4/fitting_data/const_data.txt**

const_data.txt

~/Dropbox/highshool_students_physics/data_analysis/project#4/const_data.txt

independent variable	average measurement	standard deviation
0.000000000000000000e+00	9.995608073198061447e+02	2.010880856634203795e+00
1.000000000000000000e+00	9.989000304105954910e+02	1.635795591692006834e+00
2.000000000000000000e+00	9.990060216805485425e+02	2.196269491332777601e+00
3.000000000000000000e+00	1.001145019684710974e+03	2.727748014799645127e+00
4.000000000000000000e+00	1.000325729760938771e+03	3.133910015053178011e+00
5.000000000000000000e+00	9.996966972703230567e+02	2.582352105425600453e+00
6.000000000000000000e+00	1.001185862556614097e+03	3.610132155324399239e+00
7.000000000000000000e+00	9.988642623323200951e+02	3.990053363012680876e+00
8.000000000000000000e+00	1.000437143482329930e+03	4.138951037265467647e+00
9.000000000000000000e+00	9.997121768891632883e+02	4.065402221831392993e+00
1.000000000000000000e+01	9.998270261017927396e+02	4.065727850605284743e+00
1.100000000000000000e+01	1.000965868351814720e+03	4.418148420465375814e+00
1.200000000000000000e+01	9.995462363367937542e+02	2.086260784909980348e+00
1.300000000000000000e+01	9.998277159350965348e+02	4.191409335069876008e+00
1.400000000000000000e+01	9.997391408396299539e+02	2.868036357268816339e+00
1.500000000000000000e+01	9.996997858726948607e+02	3.100581750743879539e+00
1.600000000000000000e+01	9.994488473562142872e+02	4.001916818957766075e+00
1.700000000000000000e+01	1.000306724780818513e+03	2.653736388738097141e+00
1.800000000000000000e+01	9.985763846692332208e+02	2.203381851084773579e+00
1.900000000000000000e+01	1.001307855283192339e+03	1.830367272051301120e+00
2.000000000000000000e+01	9.994477788298243013e+02	3.733641562551535564e+00
2.100000000000000000e+01	1.001323711961507342e+03	2.828454877578798765e+00
2.200000000000000000e+01	9.989779317670313503e+02	2.992168487437034230e+00
2.300000000000000000e+01	9.989108166430121400e+02	4.285277418619901191e+00
2.400000000000000000e+01	9.996794307426688420e+02	2.803714930261759442e+00
2.500000000000000000e+01	9.995316088565639348e+02	3.519255602155442642e+00
2.600000000000000000e+01	1.001489465965241038e+03	4.293321083141394823e+00
2.700000000000000000e+01	9.990306379092597808e+02	2.485797284494362103e+00
2.800000000000000000e+01	9.992218459646275051e+02	2.108402591512725799e+00
2.900000000000000000e+01	1.000751406739915751e+03	3.220350739074319790e+00
3.000000000000000000e+01	1.000517685400707251e+03	3.036311141027919547e+00
3.100000000000000000e+01	1.000653489026880834e+03	1.864845433477076986e+00

to load, you can see the following code

```
filename = 'const_data.txt'
const_data = np.loadtxt(filename)
print("shape(const_data) = ",np.shape(const_data))
Xs,Ys,sigs = const_data.T
print("shape(Xs) = ",np.shape(Xs))
print("shape(Ys) = ",np.shape(Ys))
print("shape(sigs) = ",np.shape(sigs))
```

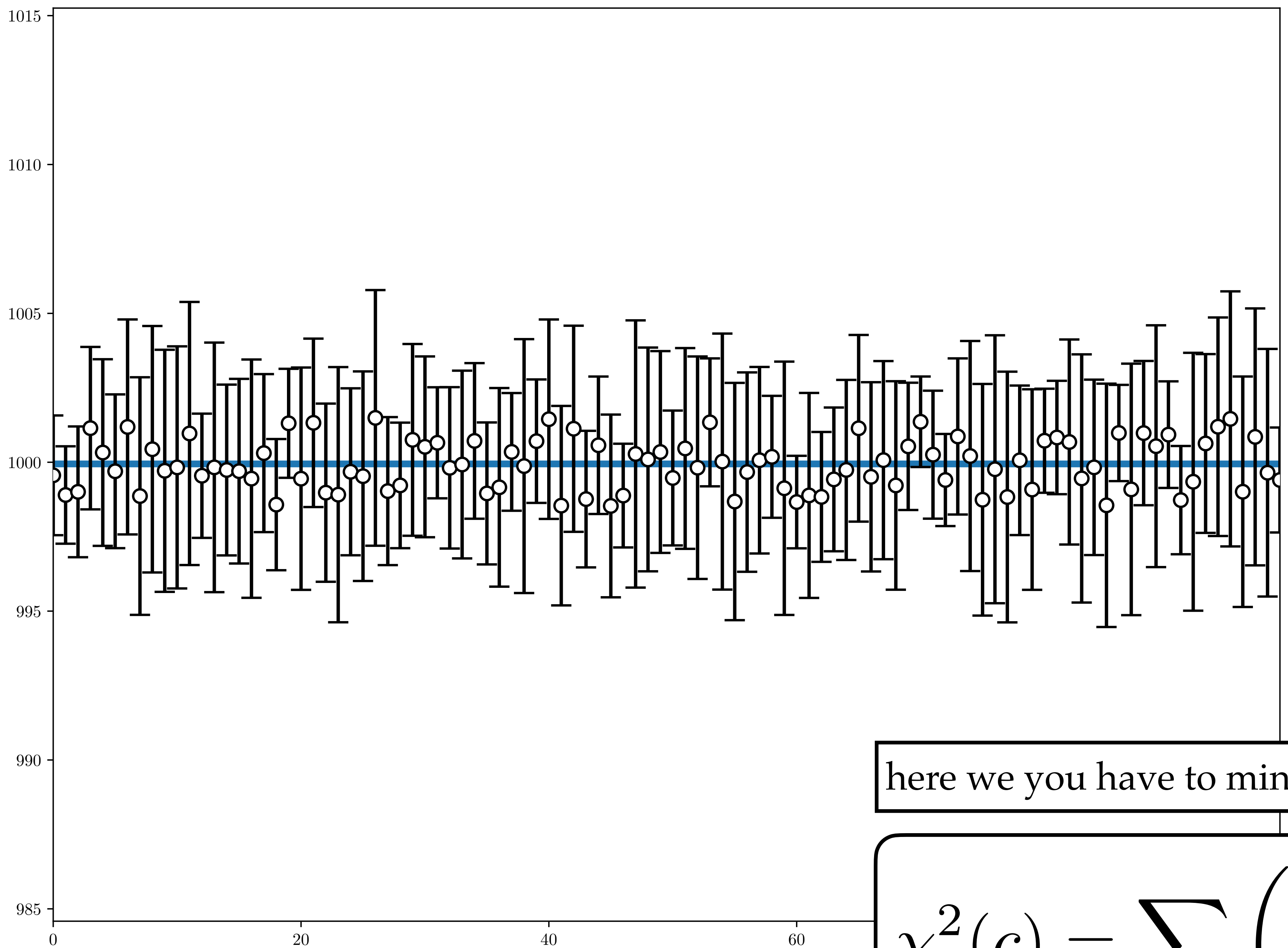
output…

```
shape(const_data) =  (100, 3)
shape(Xs) =  (100,)
shape(Ys) =  (100,)
shape(sigs) =  (100,)
```

EXERCISE #2 - WARM UP...FIT A CONSTANT - WHAT TO EXPECT

Load the data in **Dropbox:/P4P_2020/project# 4/fitting_data/const_data.txt**

Fit the data to a constant. Follow up, how does this constant compare to the average?



here we you have to minimize

$$\chi^2(c) = \sum_i \left(\frac{\bar{Y}_i - c}{\sigma_i} \right)^2$$

EXERCISE #3 - FIT A STRAIGHT LINE

Load the data in **Dropbox:/P4P_2020/project# 4/fitting_data/MN_data.txt**

m_π = independent variable

standard error

~/Dropbox/python4physics/projects_week4/fitting_data/MN_data.txt

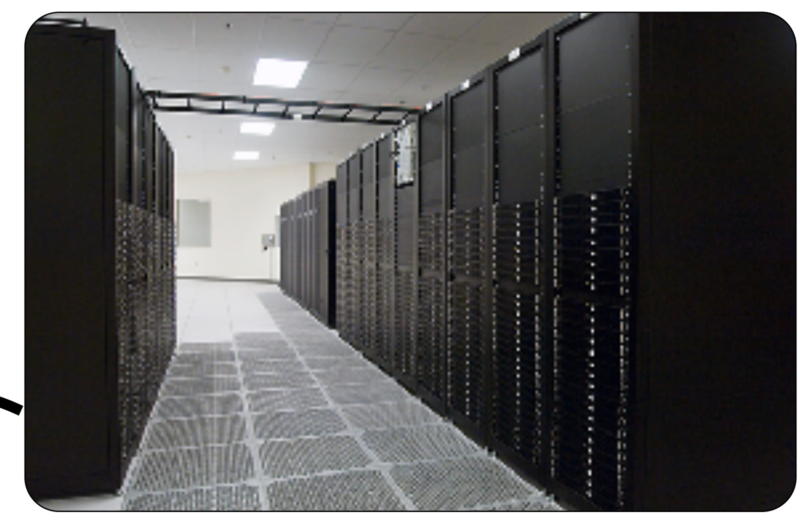
173.	984.5	8.5
249.	1055.0	7.0
265.	1069.5	27.5
293.	1095.0	7.0
293.	1098.5	8.5
304.	1111.0	20.0
324.	1121.5	19.5
333.	1141.5	5.5
343.	1141.0	19.0
349.	1162.0	5.0
356.	1157.0	6.0
399.	1208.5	4.5
407.	1205.0	19.0
423.	1230.5	3.5
440.	1234.0	19.0
496.	1287.5	6.5
498.	1291.5	18.5
577.	1375.0	18.0
565.	1391.5	5.5
543.	1345.0	19.0
597.	1387.5	9.5
688.	1501.0	10.0
758.	1566.0	7.0
680.	1568.5	12.5

mN = average measurement

lattice QCD results

$$\mathcal{L}_{QCD} = \bar{\psi}_q \left(i \not{D} - m_q \right) \psi_q - \frac{1}{4} \mathrm{tr}\,(\mathrm{GG})$$

input: quark masses - m_q



output: observables

$$(m_\pi, m_N, \ldots, \text{“nuclear physics”})$$

EXERCISE #3 - FIT A STRAIGHT LINE

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680.	1568.5	12.5

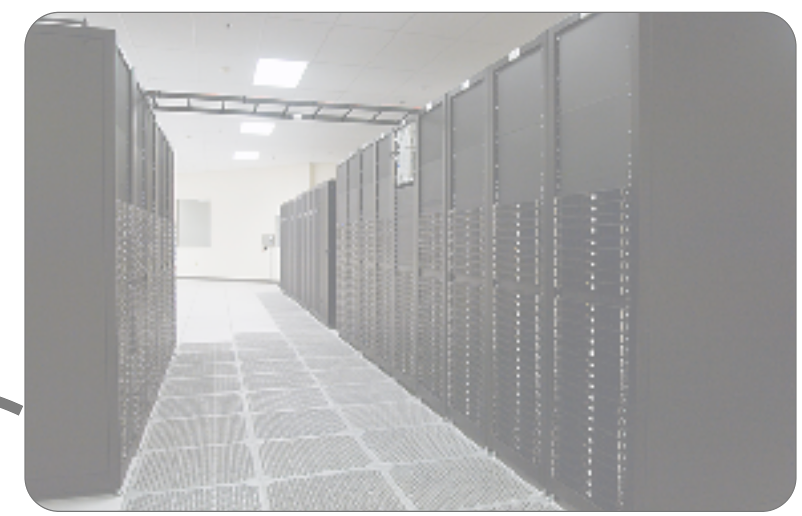
mN = average measurement

real "data"

lattice QCD results

$$\mathcal{L}_{QCD} = \bar{\psi}_q \left(i \not{D} - m_q\right) \psi_q - \frac{1}{4}\mathrm{tr}\left(GG\right)$$

input quark masses - m_q



output: observables

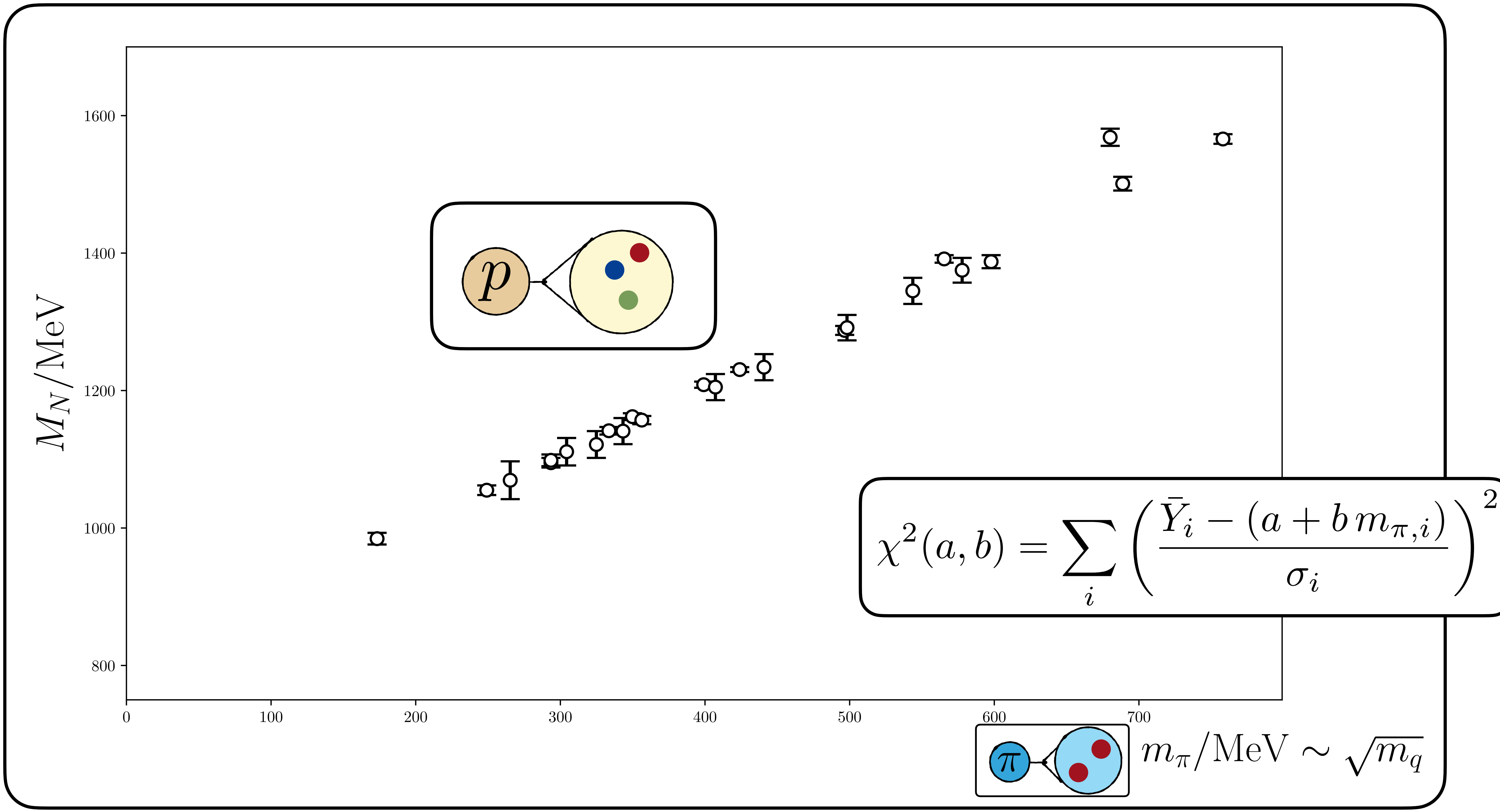
$$\left(m_\pi, m_N, \dots, \text{“nuclear physics”}\right)$$

EXERCISE #3 - FIT A STRAIGHT LINE

Load the data in **Dropbox:/P4P_2020/project# 4/fitting_data/MN_data.txt**

Fit to a straight line assuming $M_N = M_0 + m_\pi b$

M_0 is the value of the mass when the Higgs does not matter! Compare this to the physical nucleon mass. How much does the Higgs contribute to our mass?



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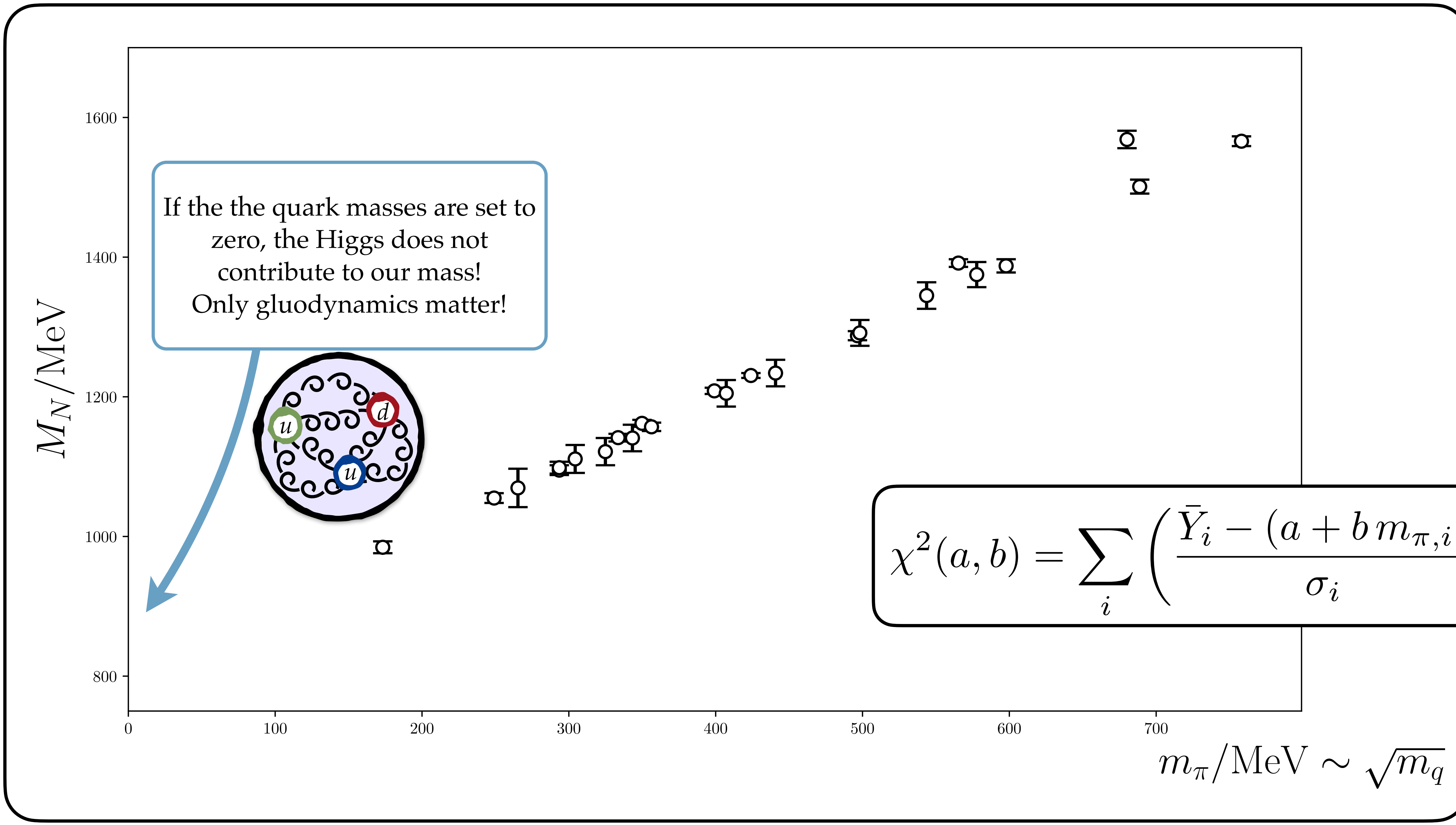
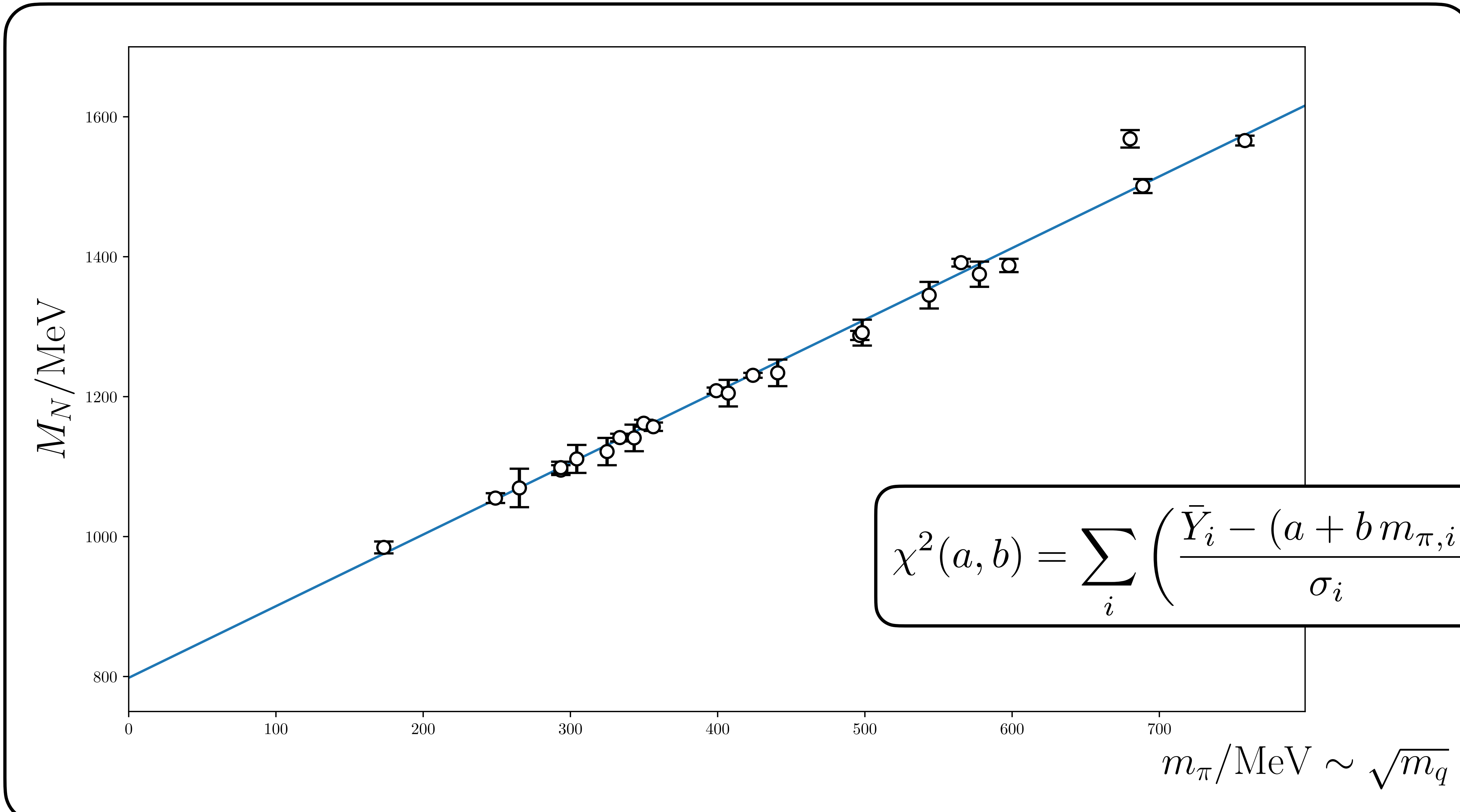


$$\chi^2(a,b) = \sum_i \left(\frac{\bar{Y}_i - (a + b\, m_{\pi,i})}{\sigma_i} \right)^2$$

Load the data in **Dropbox:/P4P_2020/project# 4/fitting_data/MN_data.txt**

Fit to a straight line assuming $M_N = M_0 + m_\pi b$

M_0 is the value of the mass when the Higgs does not matter! Compare this to the physical nucleon mass. How much does the Higgs contribute to our mass?

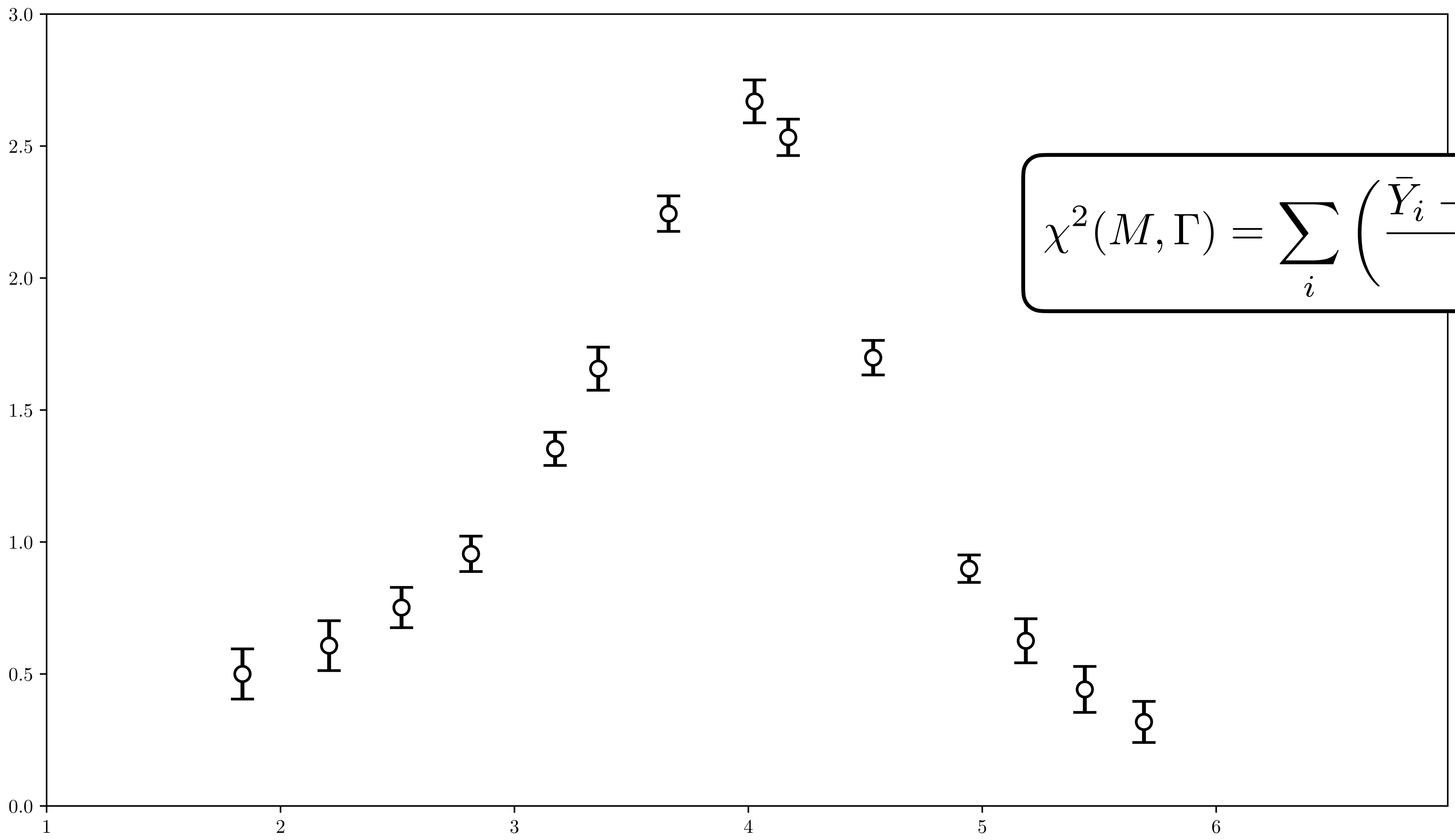


$$\chi^2(a,b) = \sum_i \left(\frac{\bar{Y}_i - (a + b\, m_{\pi,i})}{\sigma_i} \right)^2$$

EXERCISE #4 - FIT A BREIT-WIGNER

Load the data in **Dropbox:/P4P_2020/project# 4/fitting_data/BW_data.txt**

Fit to a Breit-Wigner. Determine the mass and width of the state

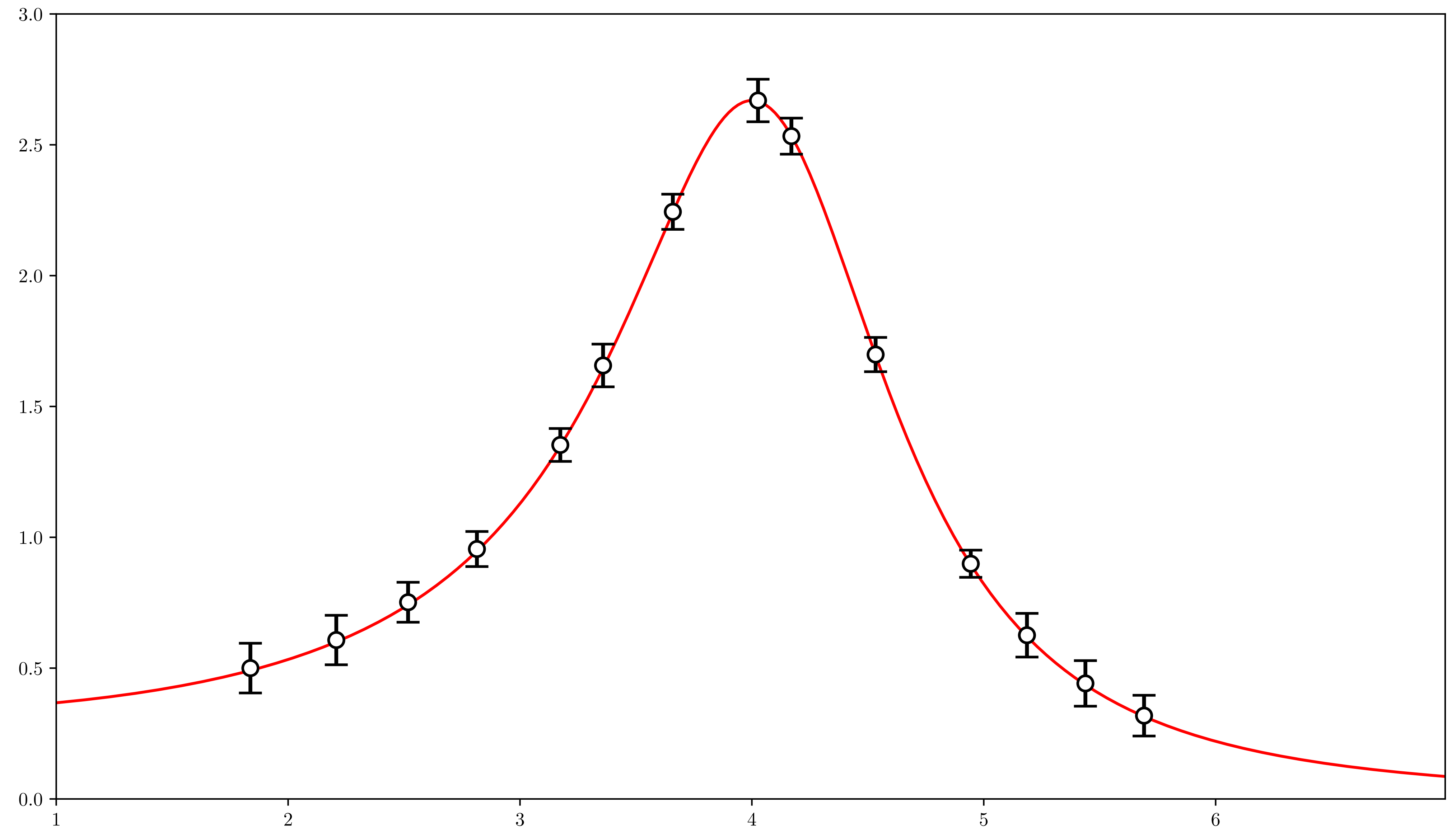


$$\chi^2(M,\Gamma) = \sum_i \left(\frac{\bar{Y}_i - P_i(M,\Gamma)}{\sigma_i} \right)^2$$

EXERCISE #4 - FIT A BREIT-WIGNER - WHAT TO EXPECT

Load the data in **Dropbox:/P4P_2020/project# 4/fitting_data/BW_data.txt**

Fit to a Breit-Wigner. Determine the mass and width of the state



Statistics:

Goodness of fit: $$\chi^2(\{c\}) = \sum_i \left(\frac{\bar{Y}_i - f(X_i, \{c\})}{\sigma_i} \right)^2$$

X_i = independent variables, Y_i =dependent variables, σ_i = errors in Y_i ,
f = function of variables $\{c\}$, which represent the expected value.

Physics:

Breit-Wigner distribution as a function of energy (E):

$$P(E) = \frac{M^3\Gamma}{(E^2 - M^2)^2 + M^2\Gamma^2}$$

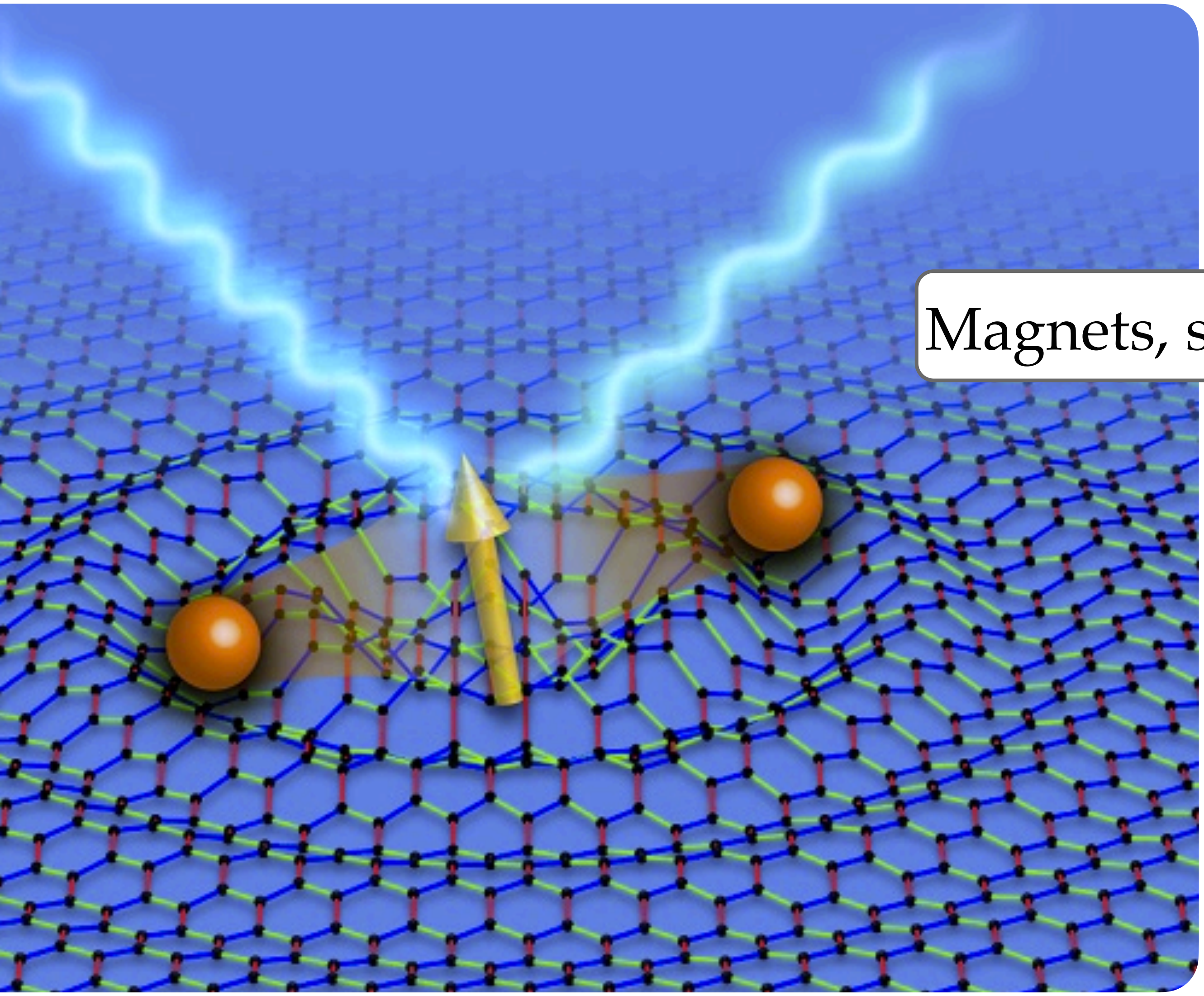
M, Γ are properties of a short-lived resonating particle.

M = is the mass of the resonance

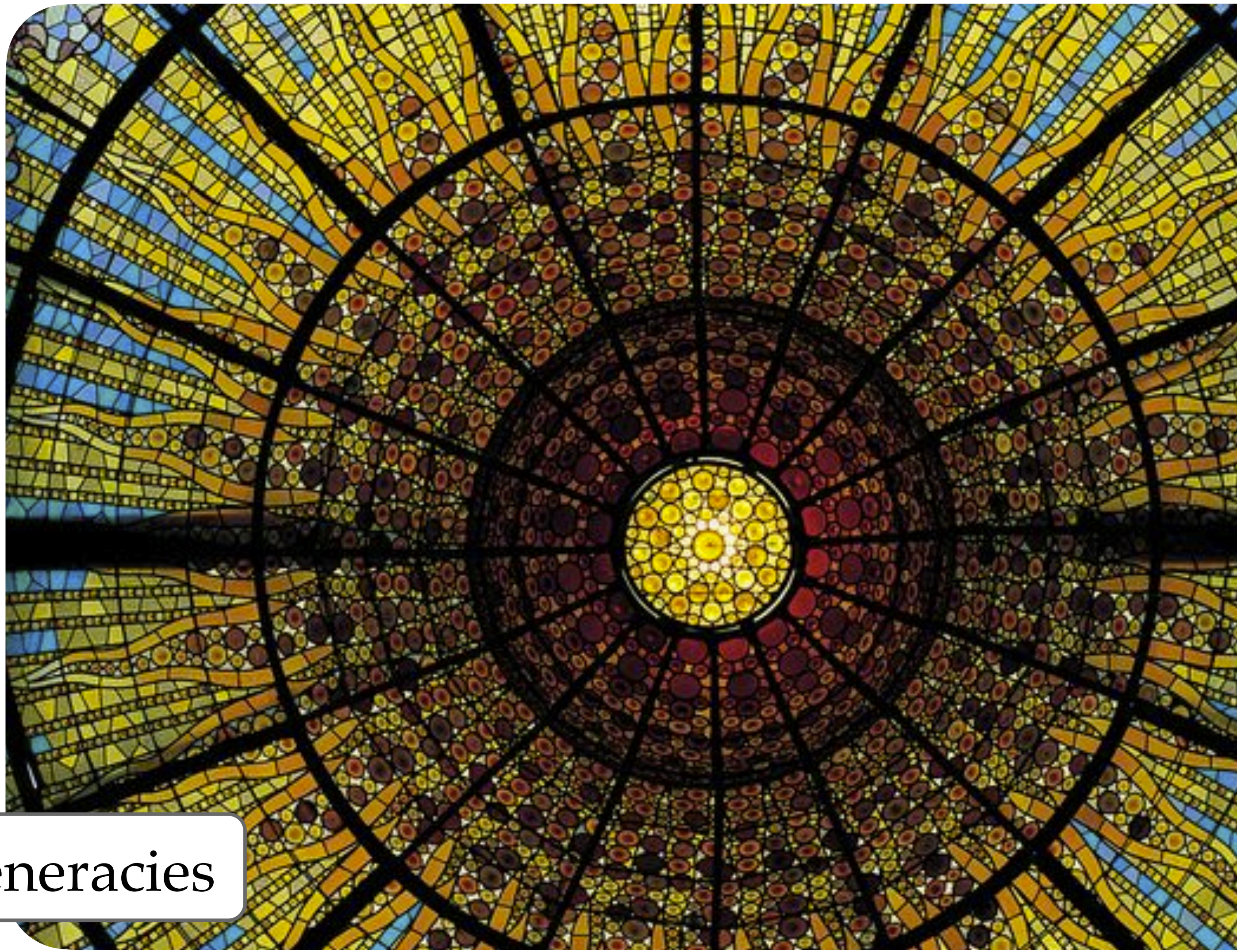
Γ = decay width of the resonance = 1/(lifetime of the resonance)


Ok, Let's
Dive in

OUTLINE FOR TODAY

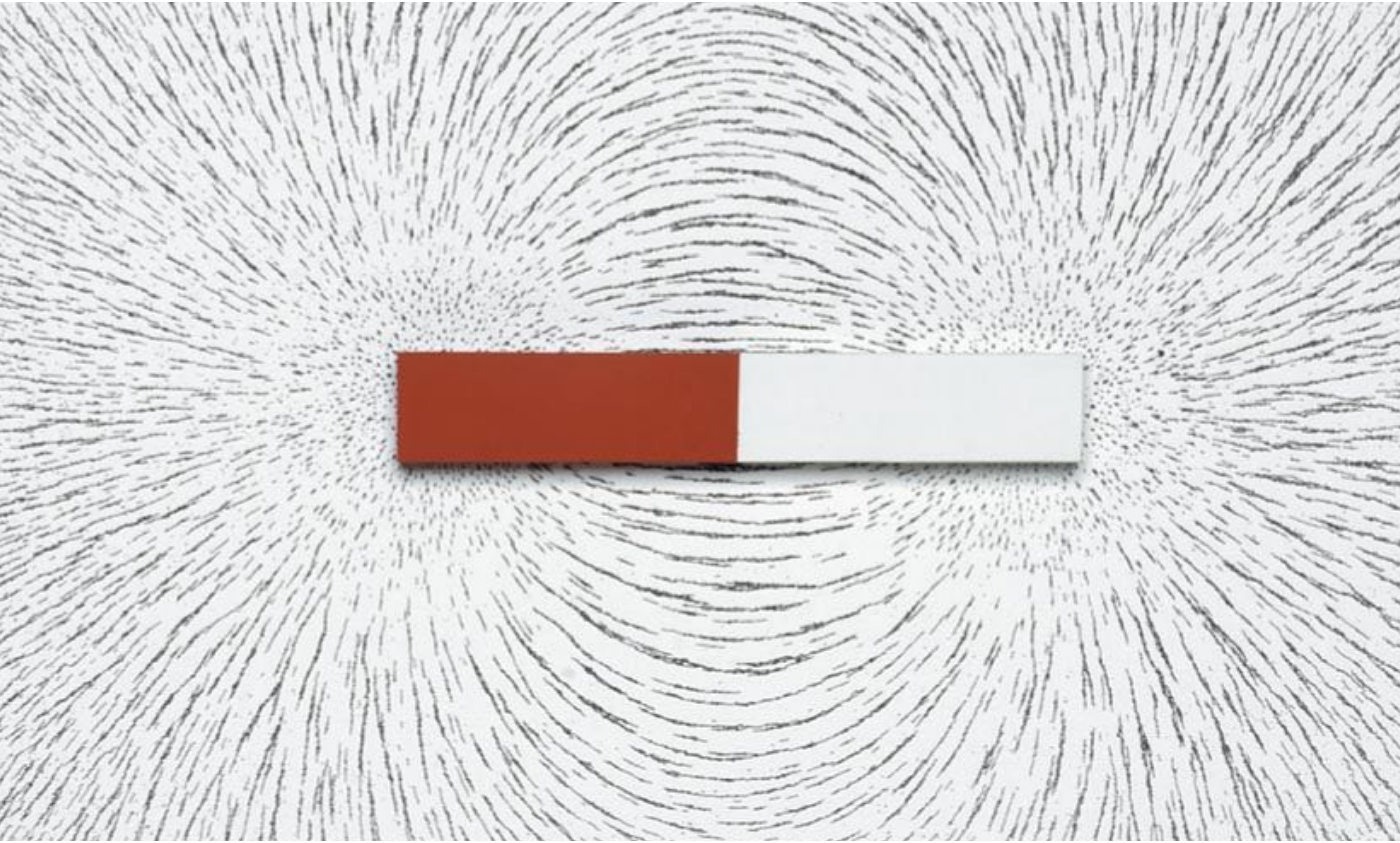


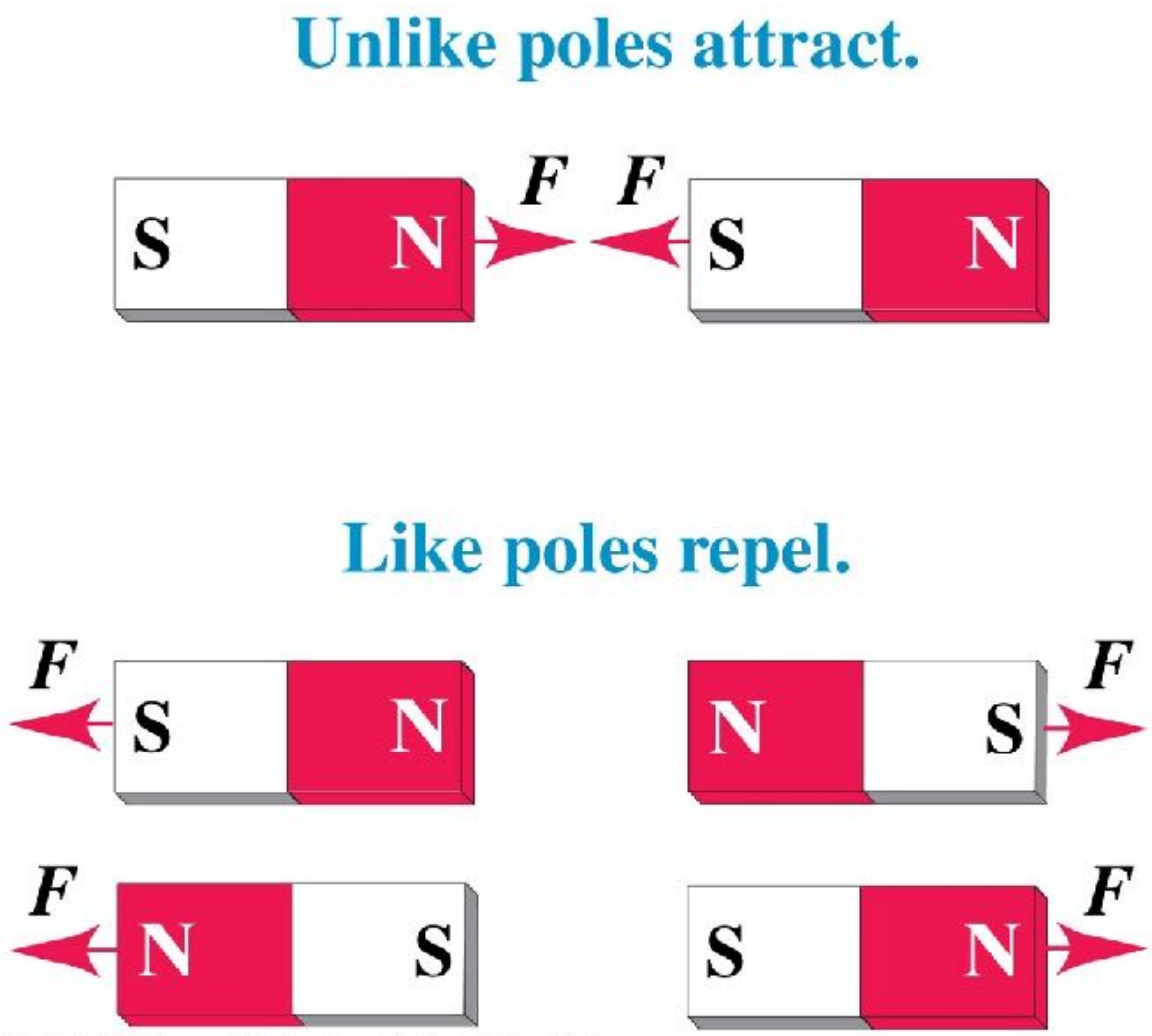
Magnets, spin, interactions



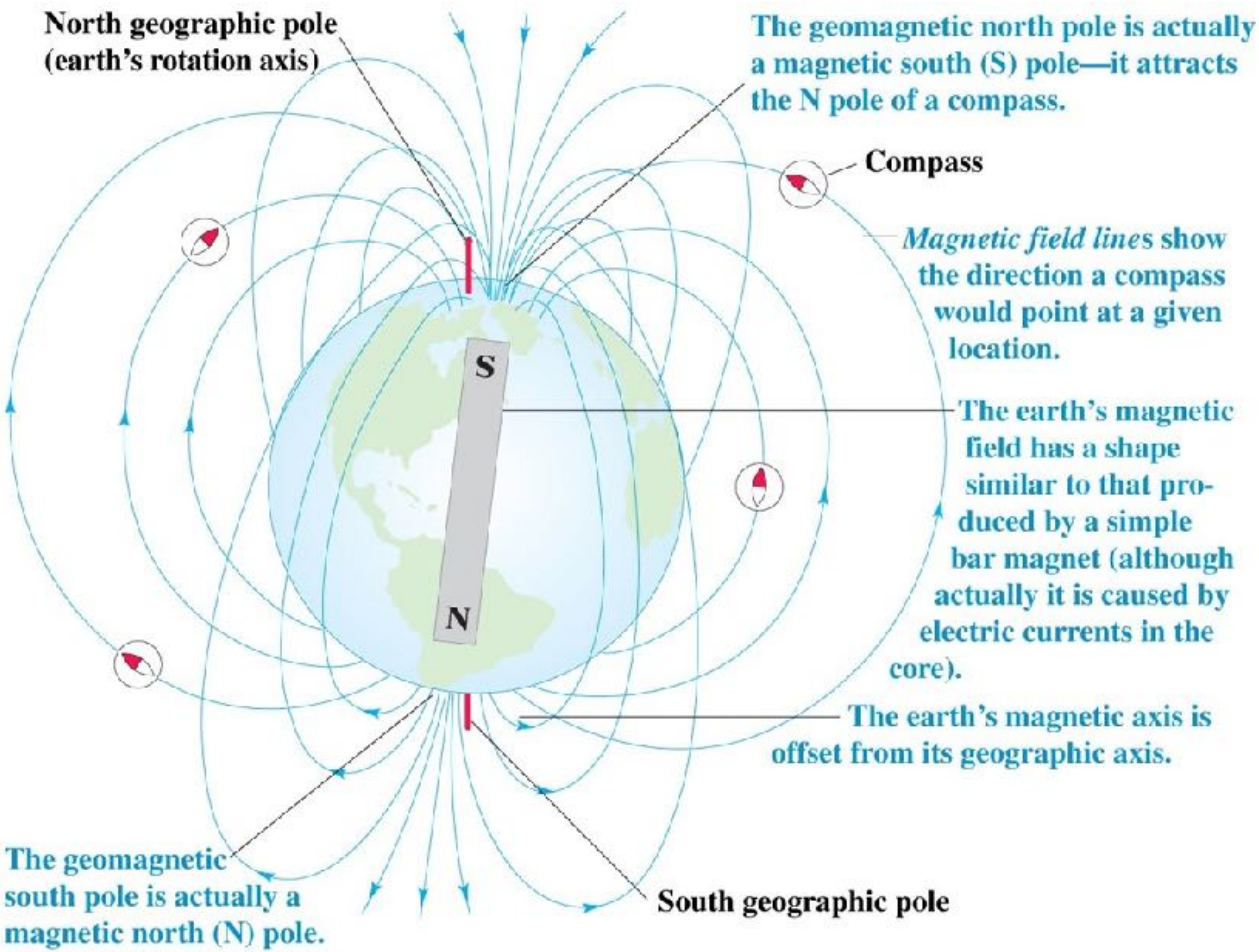
Symmetries, degeneracies

BAR MAGNET & IRON FILINGS

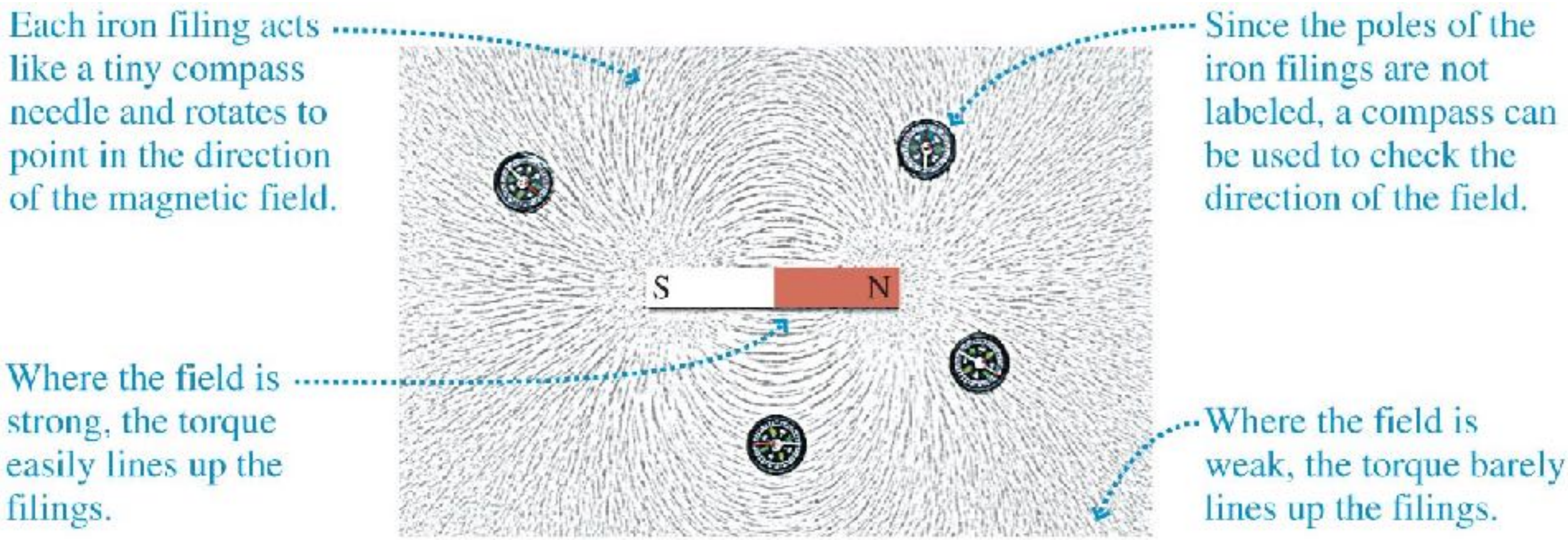



Unlike poles attract.
S
N
F
F
S
N
Like poles repel.
F
S
N
N
S
F
F
N
S
S
N
F

THE EARTH'S MAGNETIC FIELD



MAGNETIC FIELDS



‘ELECTRO’-MAGNETISM

➜ is there a connection between electricity and magnetism ?

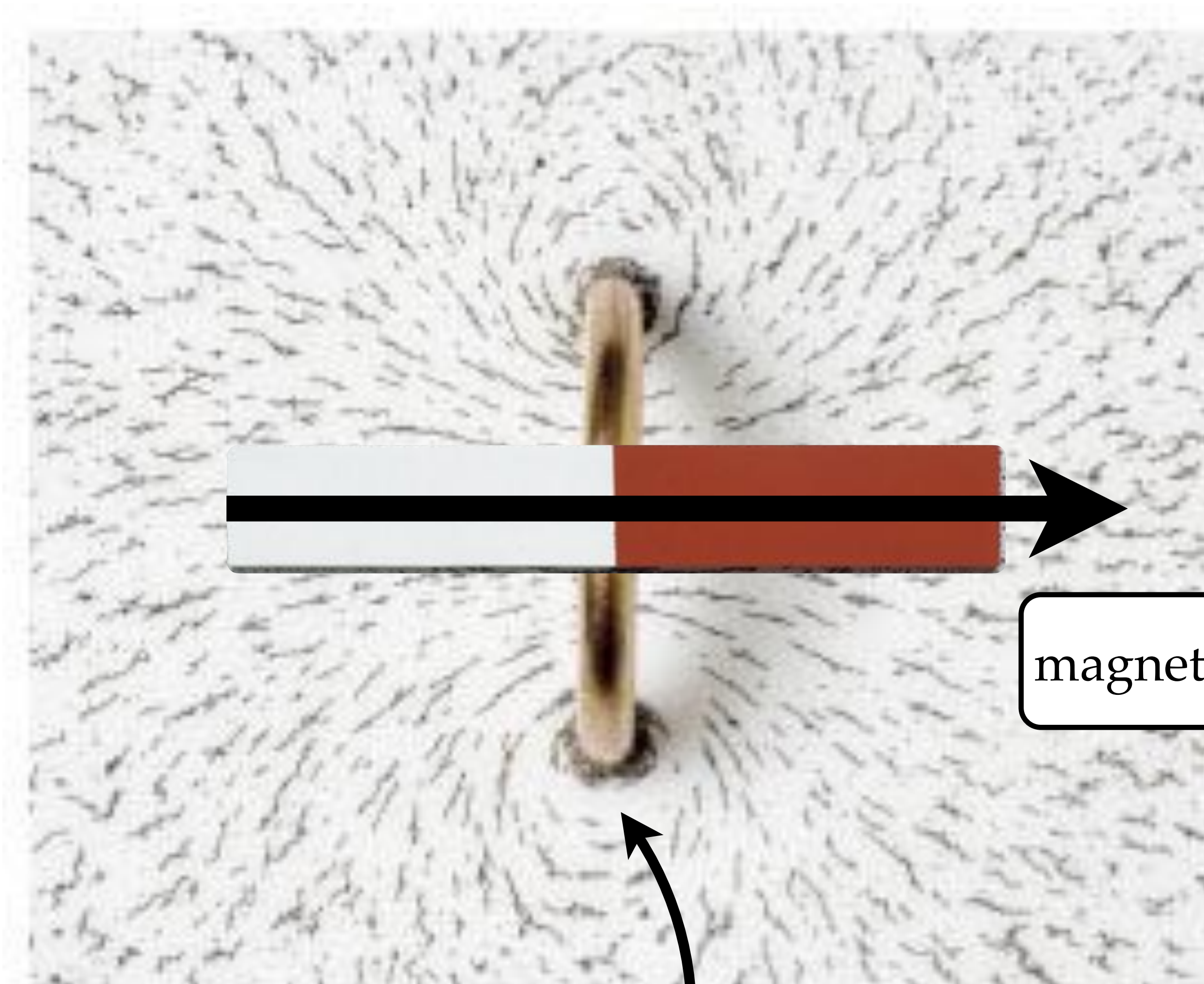
➜ a loop carrying a large current

currents in a loop, behave like magnets…

'ELECTRO'-MAGNETISM

➜ is there a connection between electricity and magnetism ?

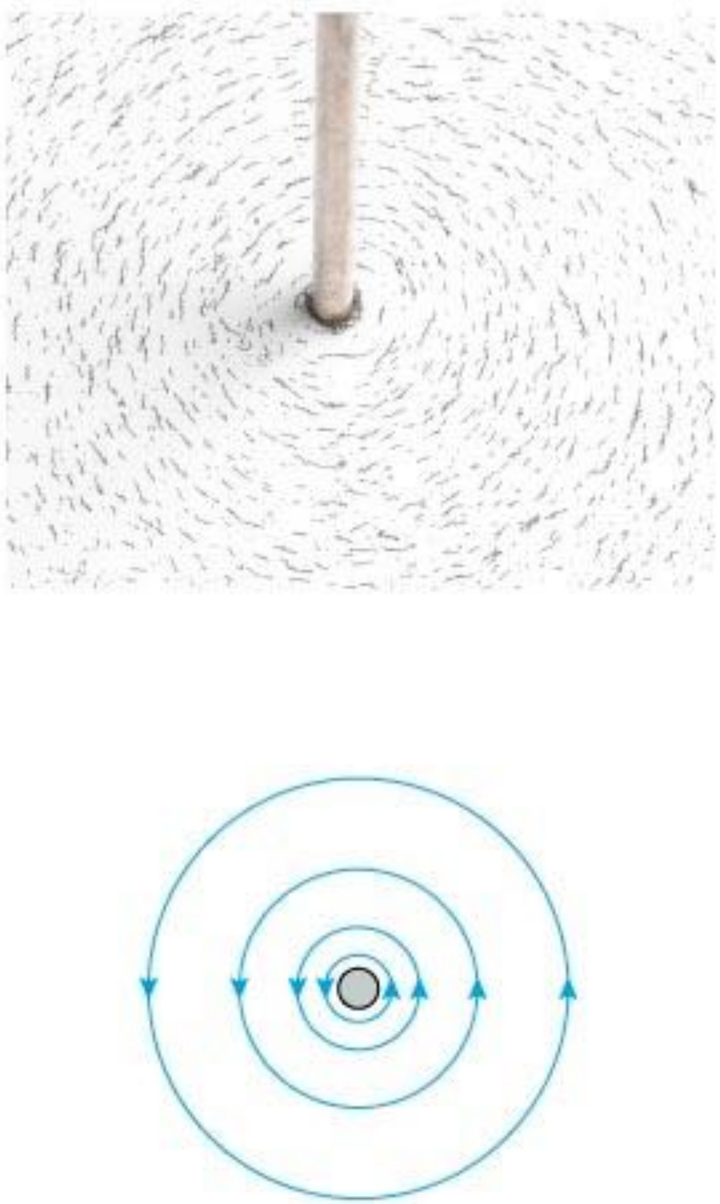
➜ a loop carrying a large current

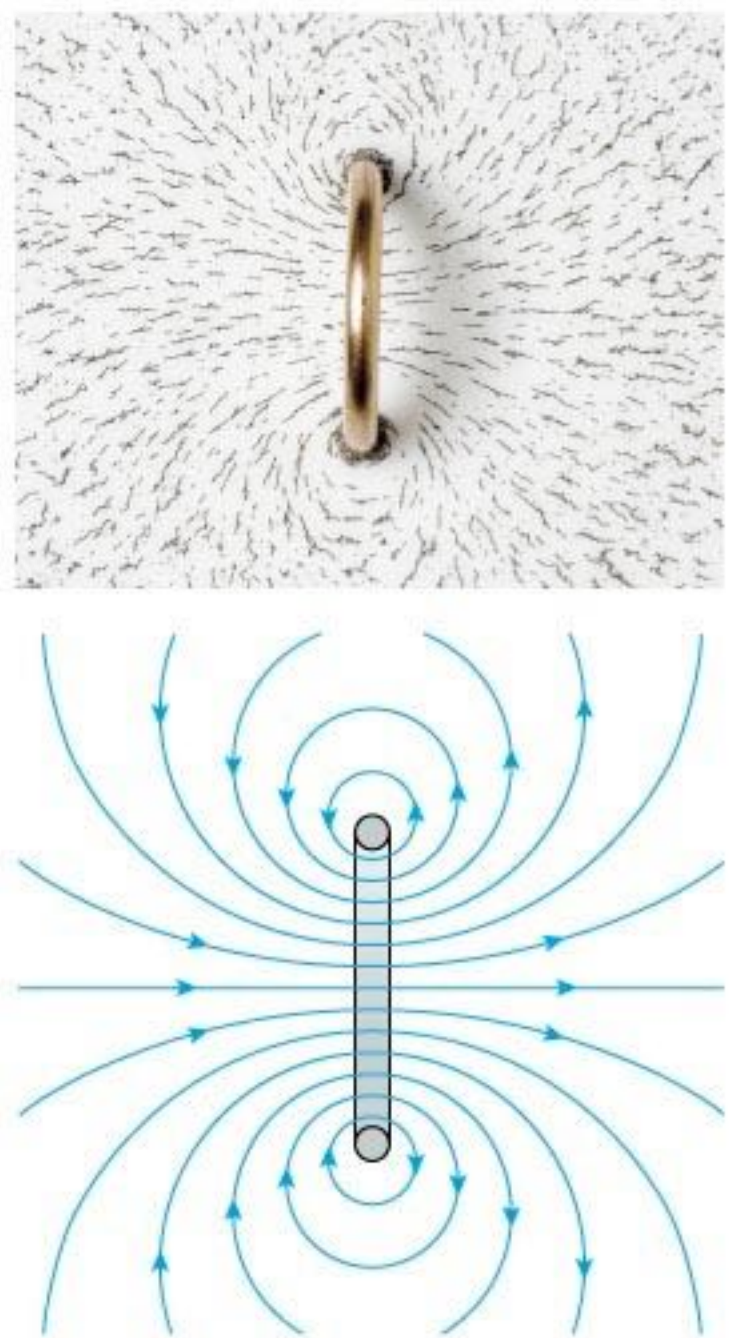


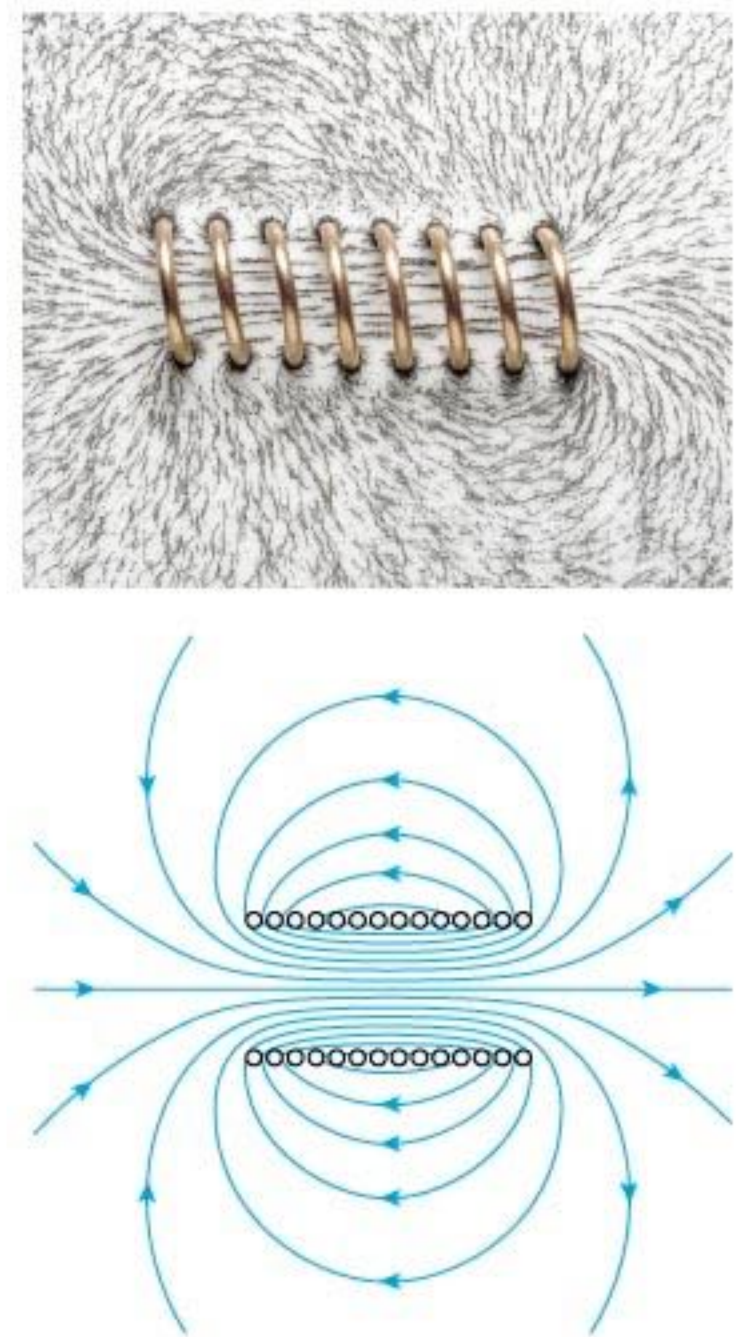
magnetic moment has a magnitude and direction

currents in a loop, behave like magnets…

MAGNETIC FIELDS



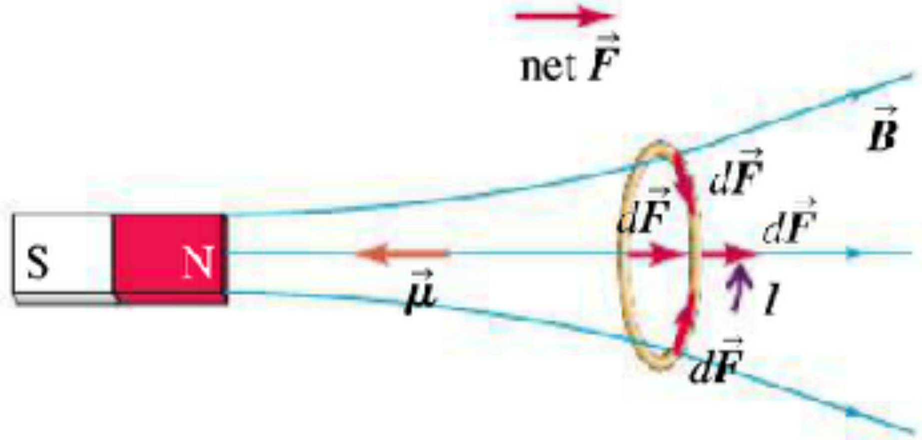


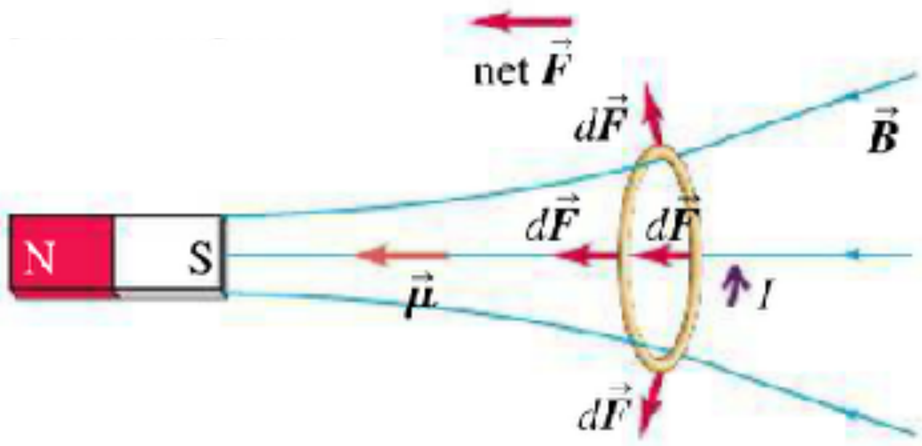


If the magnetic moment of a dipole is anti-aligned with a field, it will a force towards where there is a lower density.

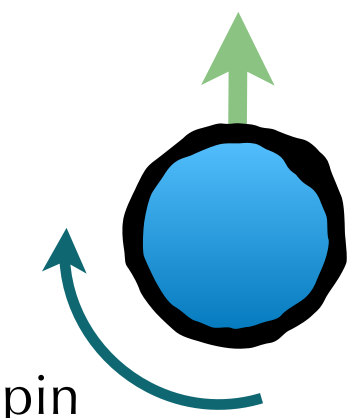
Conversely, if the moment is aligned with the field, it will experience a force towards the higher density.

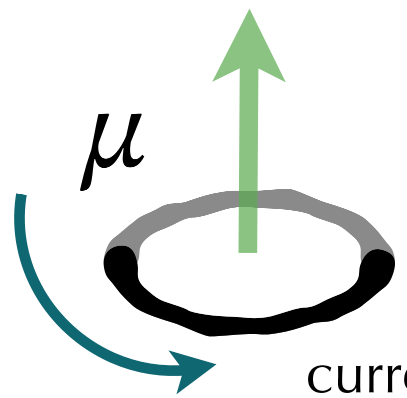
In other words, they behave like magnets!



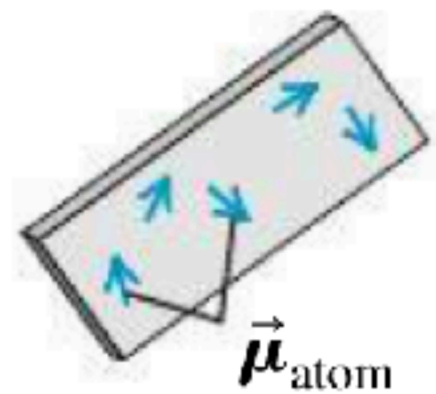


This then allows us to paint a microscopic picture of magnets. If we think of electrons as little spheres spinning about their axis, this would result in a current and consequently a magnetic dipole

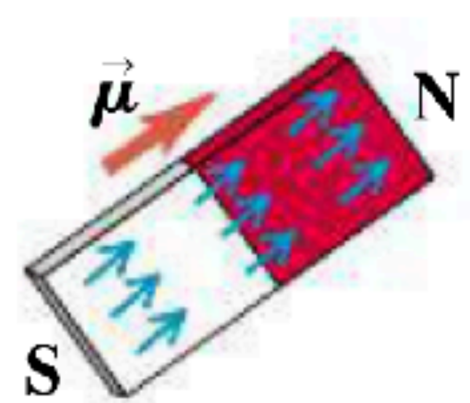


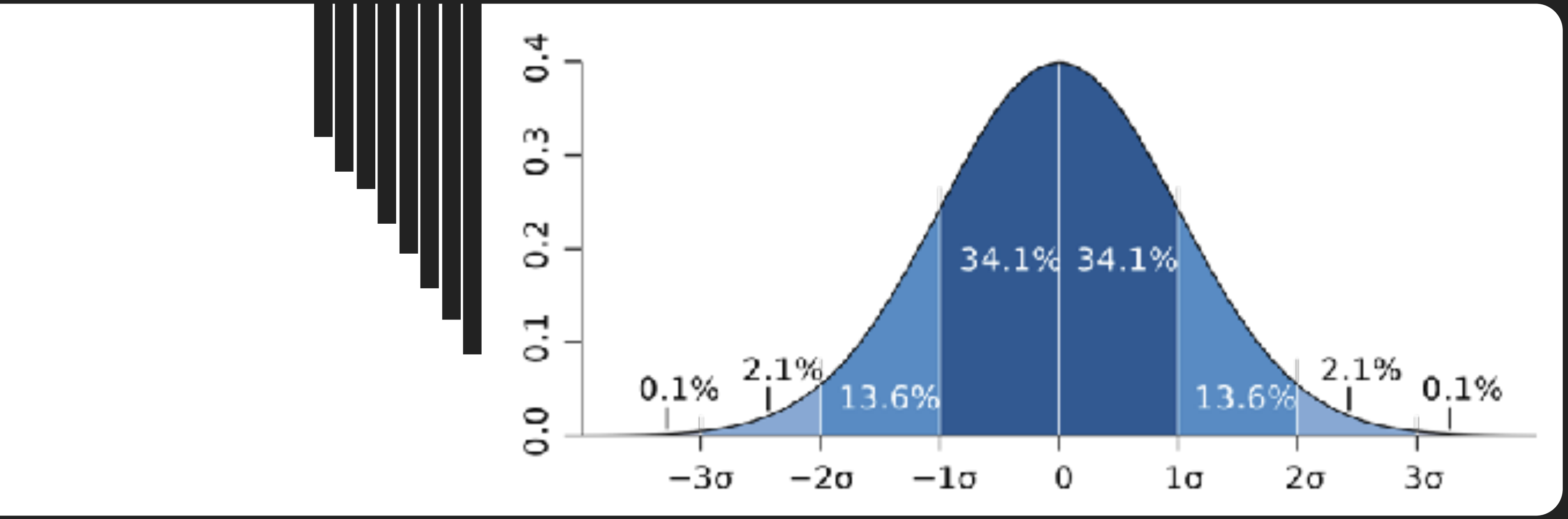


So, **<u>unmagnetized material</u>** is made of magnetic moments there are not aligned in any direction



<u>Magnetized material</u> is that where the moments have been aligned by an external field, and then persist to be aligned due to their internal interactions





R. BRICEÑO, T. ROGERS

MAGNETS AND SYMMETRIES

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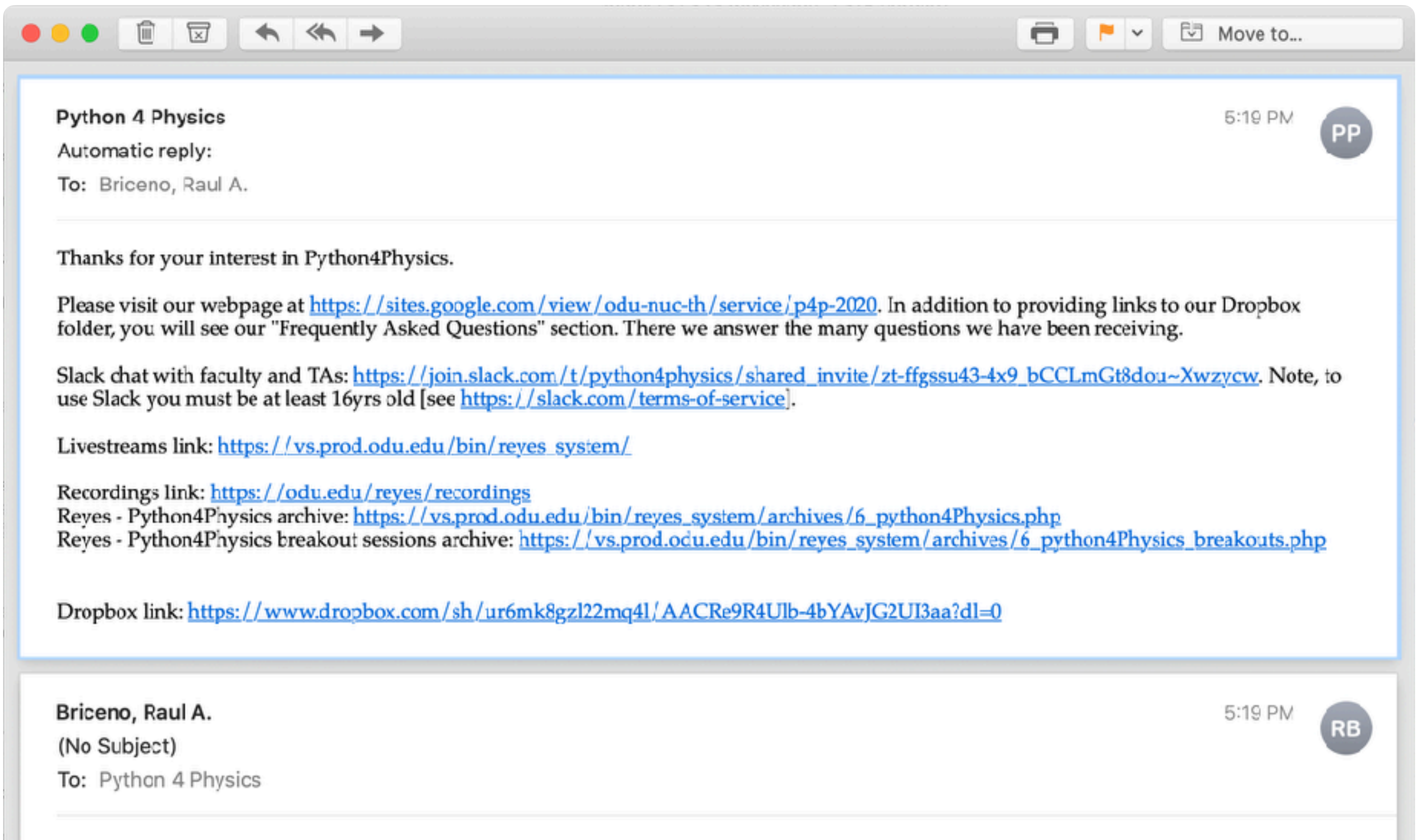

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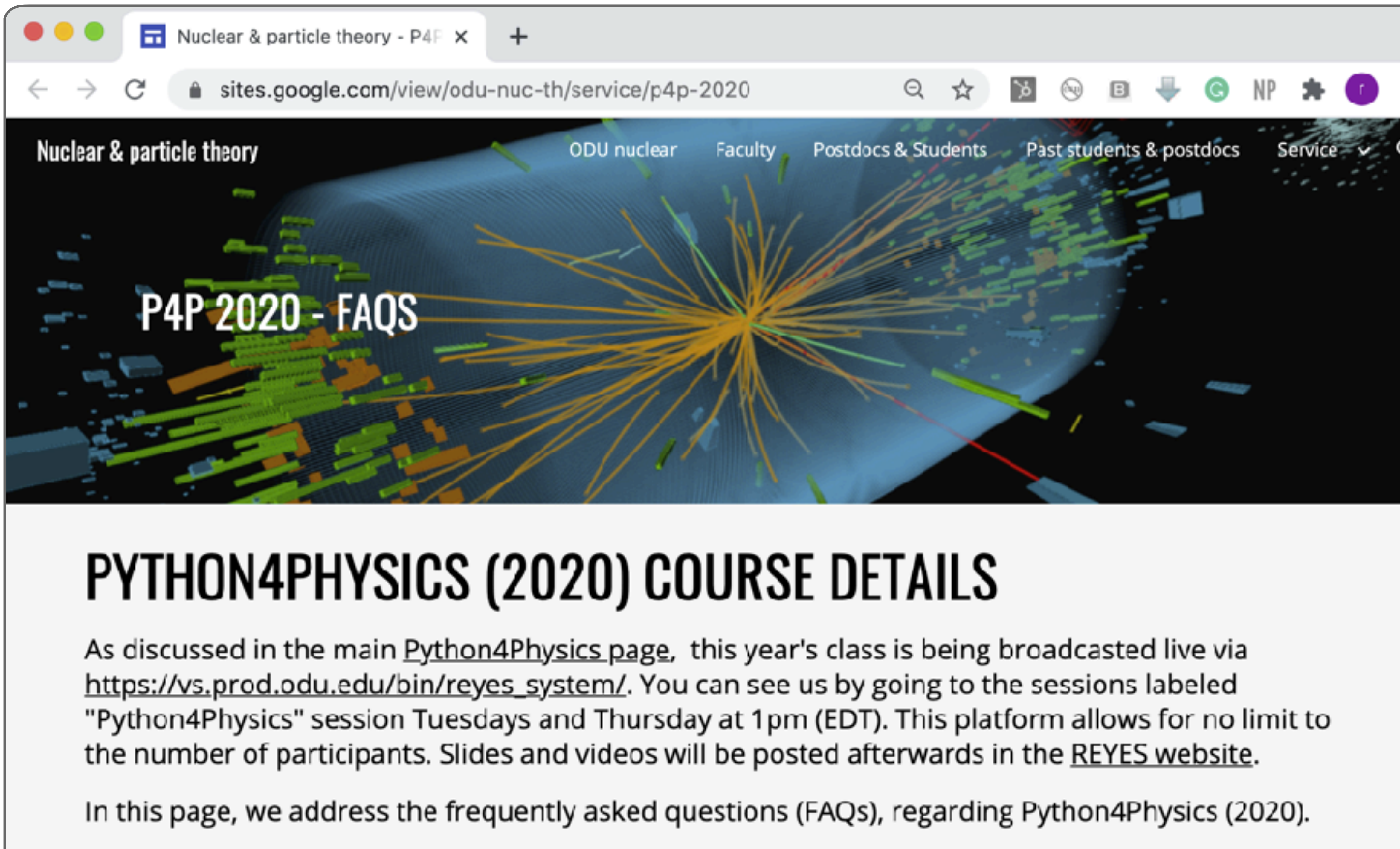

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Dropbox for students, email us! Subject: “Dropbox access”

To understand spins inside material, it is useful to construct a simple model. The most famous of which is the **Ising model [**https://en.wikipedia.org/wiki/Ising_model**]**, named after **Ernst Ising**.

Ising solved the simplest version of this model in 1-dimension (1D), which we consider here.

In the Ising model, spins are fixed. They can either **point up (+1)** or **down (-1)**. Spin inside material can either ***align*** or ***anti-align***.

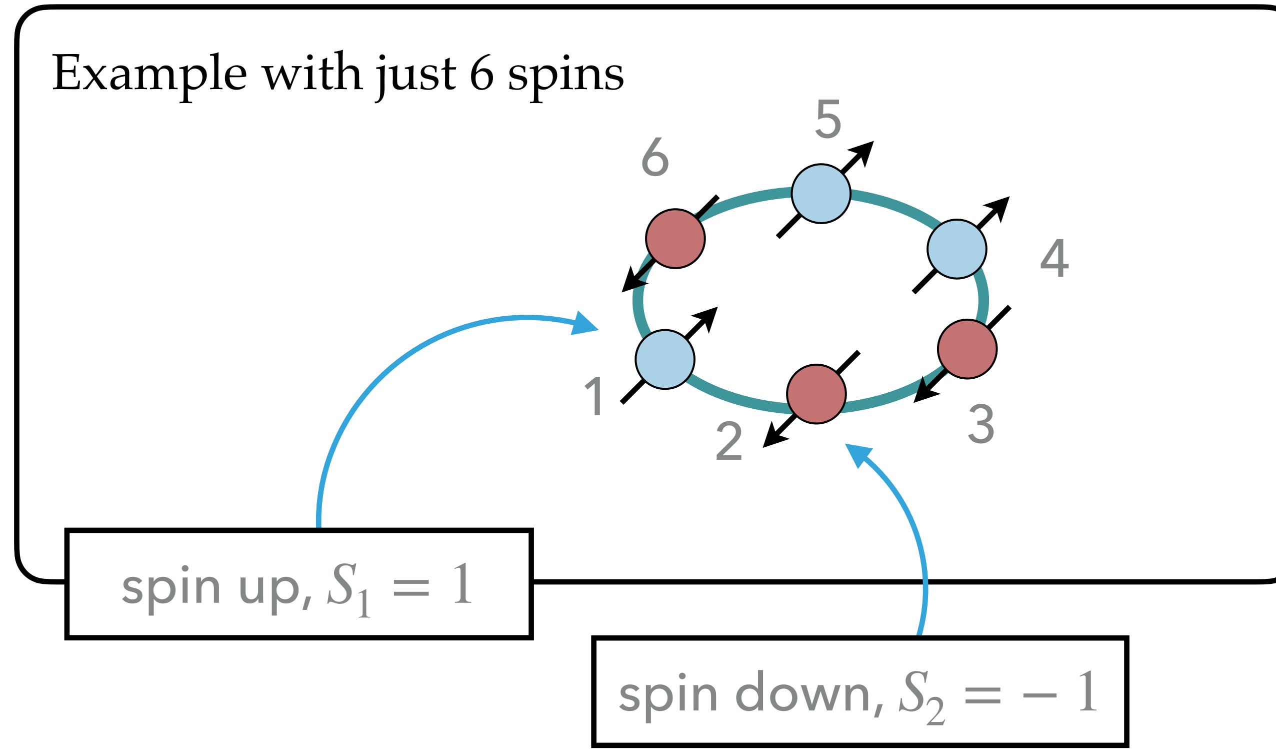
Depending on the material, certain alignment of spins, it might be favorable or dis-favorable for spins to align. This would manifest itself in the energy stored or the energy required to put the systems into a given configuration.

Ernst Ising [1900-1998]

ISING MODEL - PART 2

Consider N spins in a ring.

Enumerate the spin from 1 to N, as shown on the example to the right for N=6. Let i be a number satisfying $1 \leq i \leq N$. Then, we will label the value of the spin for that element in the ring as S_i.



In the example, we have N = 6, and the following values for the individual spins $S_1 = 1,\ S_2 = -1,\ S_3 = -1,\ S_4 = 1,\ S_5 = 1,\ S_6 = -1.$

With this, we can make a fairly general model for the energy of a given configuration of spins:

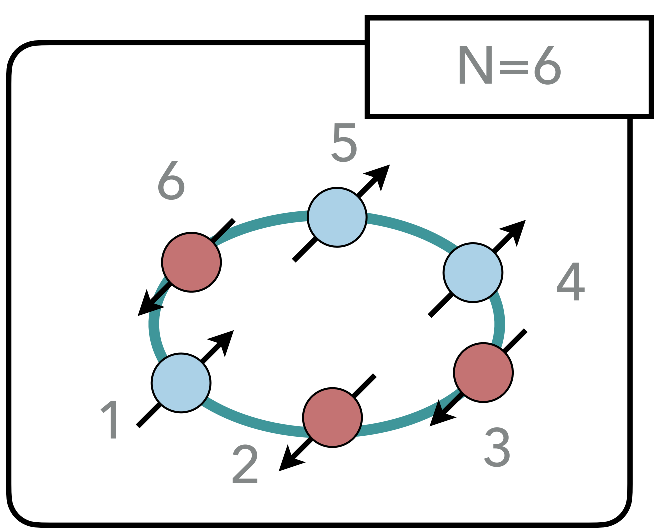
$$E(a,b,c) = a\sum_{i=1}^{N} S_i\, S_{i+1} + b\sum_{i=1}^{N} S_i\, S_{i+2} + c\sum_{i=1}^{N} S_i$$

a, b, c are constants that depend on the properties of the system. Here, we will consider different scenarios where we choose different values for these.

To understand this, we can consider a value for i, then the first term, $S_i S_{i+1}$, means that one must multiply the two values of the spin together. For this to make sense, we need to define $N+1=1,\ \ N+2=2$, This is referred to as ***"periodic boundary conditions"***.

For example, here are the numbers for the example shown in the figure:

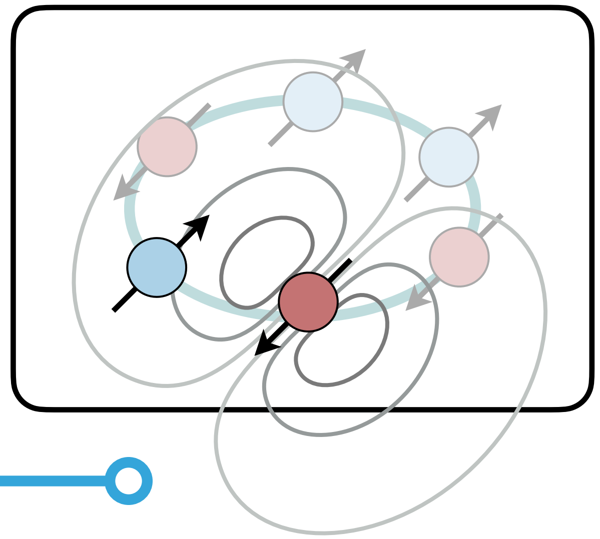
i	$i+1$	$i+2$	S_i	S_{i+1}	S_{i+2}	S_iS_{i+1}	S_iS_{i+2}
1	2	3	1	-1	-1	-1	-1
2	3	4	-1	-1	1	1	-1
3	4	5	-1	1	1	-1	-1
4	5	6	1	1	-1	1	-1
5	6	1	1	-1	1	-1	1
6	1	2	-1	1	-1	-1	1



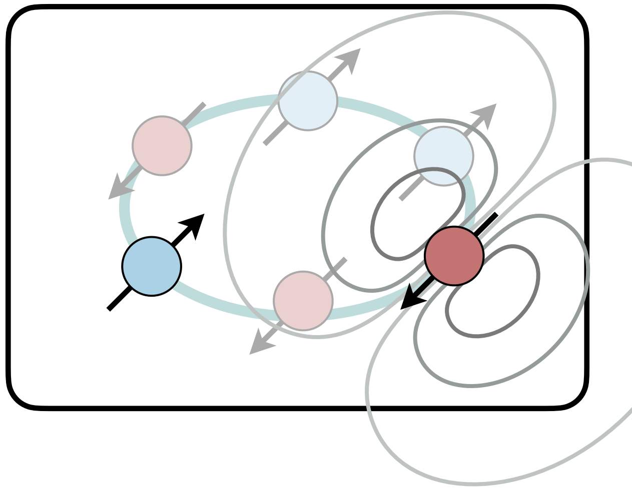
Let us gain from intuition for the physics of these terms,

Nearest neighbors: First, let us consider the first term, $E_a = a \sum_i S_i S_{i+1}$. This term tells us that each spin experiences the field generated by its closest neighbor.

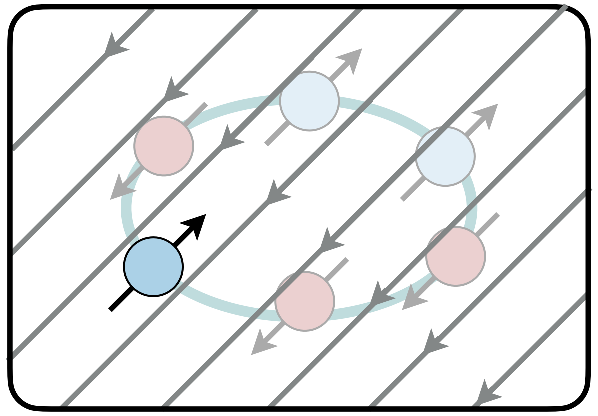
The strength with which this contributes to the energy, depends on the values of a and the spins.



Next-to-nearest neighbors: next, we consider the second term, $E_b = b \sum_i S_i S_{i+2}$. This is similar to the one above, except now a given spin is feeling the field generated by a spin that is two slots away. Again, the strength of this effect on the energy of the system depends on a given variable b and the spins.



Background field: Lastly, we have the term $\Delta E_c = c \sum_i S_i$. This accounts for the possibility that the there might an external field, say for the earth or a big magnet, and these spins field the effect from it. Again, this depends on the value of c considered.



SYMMETRIES - PART 1

In what follows, we will be determining the energies for the Ising model for a variety of different scenarios, but before we do, let's introduce some concepts. These are symmetry and degeneracy.

Symmetry: Symmetry is one of the most powerful concepts in physics. It has guided some of the major insights in physics in the last century.

Emmy Noether

"She was described by Pavel Alexandrov, Albert Einstein, Jean Dieudonné, Hermann Weyl and Norbert Wiener as the most important woman in the history of mathematics."

"Noether's theorem explains the connection between symmetry and conservation laws."

Simply put, one the most important Mathematical physicist of the 20th century.

F. Ortega-Gama

Student - William & Mary

Symmetries and how to use them in physics 07/24

WILLIAM & MARY

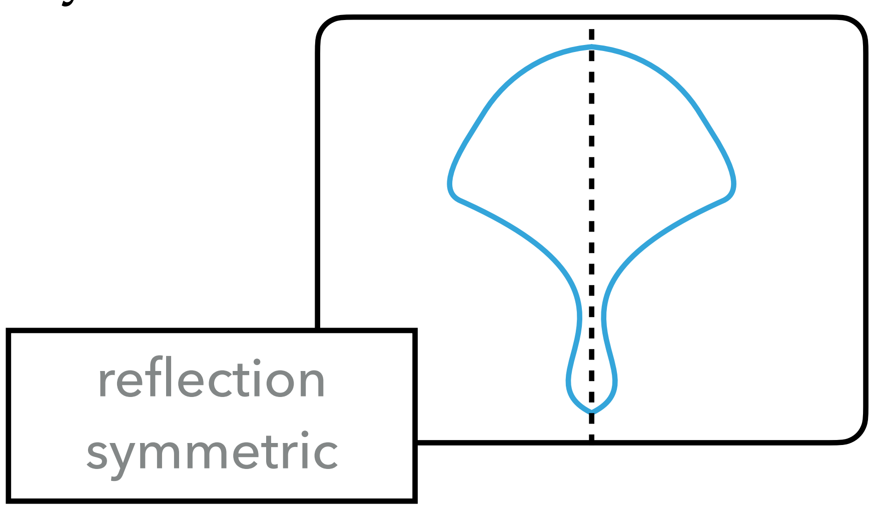
CHARTERED 1693

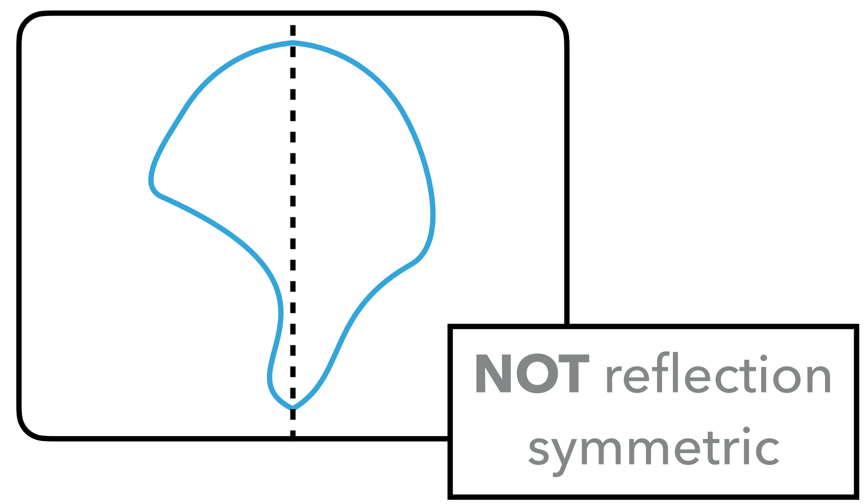
SYMMETRIES - PART 1

In what follows, we will be determining the energies for the Ising model for a variety of different scenarios, but before we do, let's introduce some concepts. These are symmetry and degeneracy.

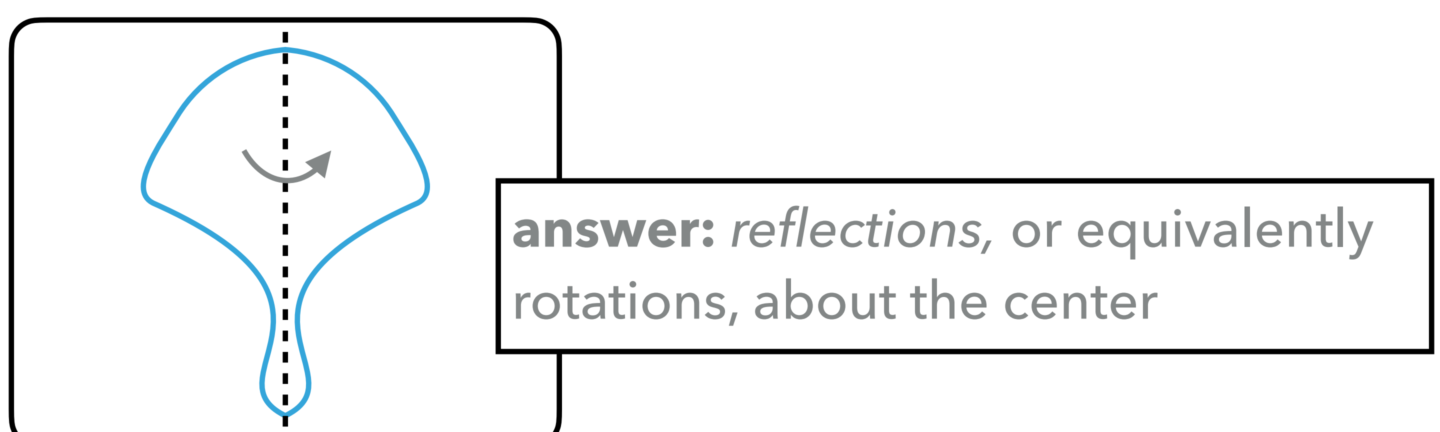
<u>Symmetry</u>: Symmetry is one of the most powerful concepts in physics. It has guided some of the major insights in physics in the last century.

One can intuitively understand symmetry by considering, for example, objects that are reflection symmetric and those that are not.





Equivalently, one can ask the question: ***"What <u>actions (or transformations)</u> leave the system <u>invariant (or unchanged)</u>?"***

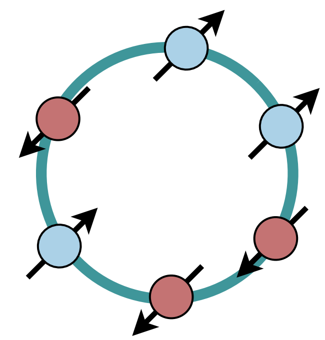


SYMMETRIES - PART 2

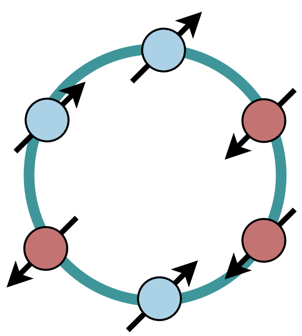
So what symmetries does our systems of spins have?

To answer this question, let us start with a simpler case where there is no external field, namely $c = 0$. In this case, the energy of the system of spins simplifies to…

$$\boxed{E(a,b,0) = a\sum_{i=1}^{N} S_i\, S_{i+1} + b\sum_{i=1}^{N} S_i\, S_{i+2}}$$

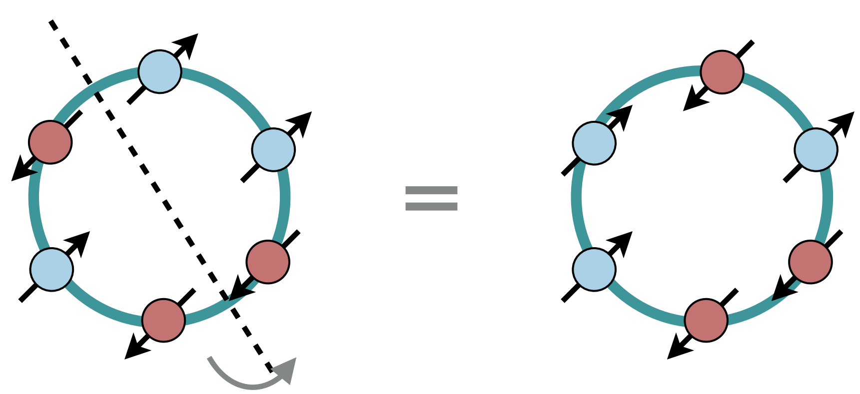
So now, let us again consider some arbitrary arrange of spins: 

Rotations:

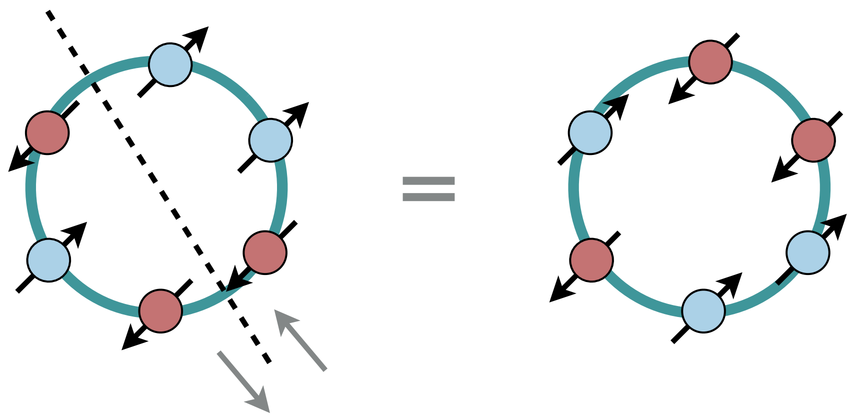


How many distinct rotations can we have? 🤔

Reflections about any axis:



Reflections about the plane. In other words, flipping over all the spins…



Is this symmetry still present if we introduce an external field or equivalently, if c is not zero? 🤔

WARM UP QUESTION

Q: If I have N aligned in a ring, in how many different possible ways can they be aligned? 🤔

WARM UP QUESTION

Q: If I have N aligned in a ring, in how many different possible ways can they be aligned?

A: $\underbrace{2 \cdot 2 \cdot 2 \cdots 2}_{N} = 2^N$

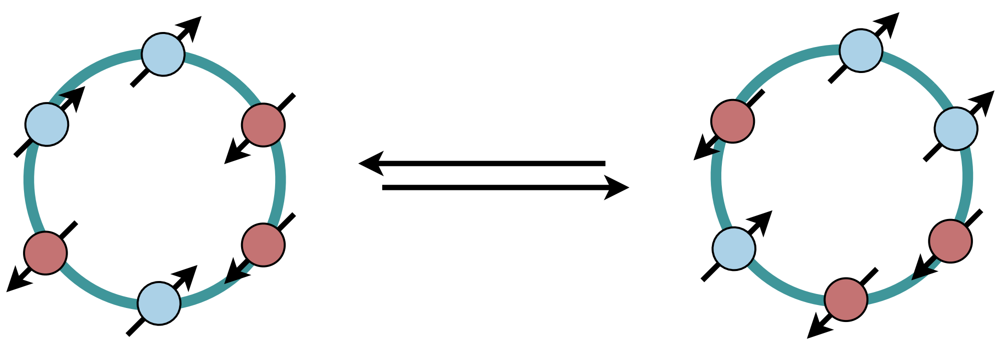
example: *consider* $N = 3$, *implies that there should be* $2^3 = 8$ *distinct configurations. Each configuration is referred to a as "state"*

$$
\begin{array}{llll}
(\uparrow, \uparrow, \uparrow), & (\uparrow, \uparrow, \downarrow), & (\uparrow, \downarrow, \uparrow), & (\uparrow, \downarrow, \downarrow), \\
(\downarrow, \uparrow, \uparrow), & (\downarrow, \uparrow, \downarrow), & (\downarrow, \downarrow, \uparrow), & (\downarrow, \downarrow, \downarrow)
\end{array}
$$

DEGENERACIES

The fact that the system has these symmetries, implies that different spin combinations would have the same energies. In quantum mechanics, this is known as a "***degeneracy***" https://en.wikipedia.org/wiki/Degenerate_energy_levels

example: these two states are degenerate for all possible values of a, b, c



Q: how are these two states related?

$$E(a,b,c) = a\sum_{i=1}^{N} S_i\,S_{i+1} + b\sum_{i=1}^{N} S_i\,S_{i+2} + c\sum_{i=1}^{N} S_i$$

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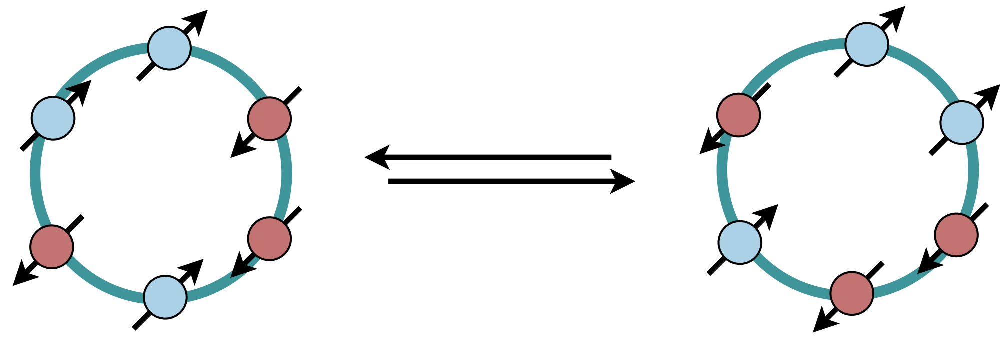


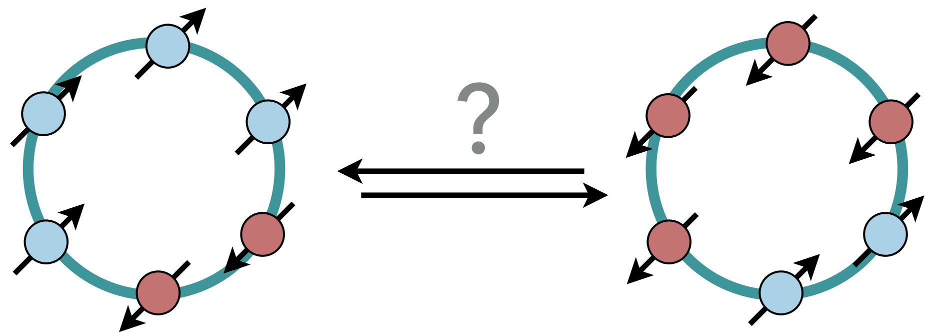
Q: how are these two states related?

A: a rotation

$$E(a,b,c) = a\sum_{i=1}^{N} S_i\,S_{i+1} + b\sum_{i=1}^{N} S_i\,S_{i+2} + c\sum_{i=1}^{N} S_i$$

WARM UP QUESTION

Q: are these two states always degenerate for all values of a, b, c?



$$E(a,b,c) = a \sum_{i=1}^{N} S_i \, S_{i+1} + b \sum_{i=1}^{N} S_i \, S_{i+2} + c \sum_{i=1}^{N} S_i$$

WARM UP QUESTION

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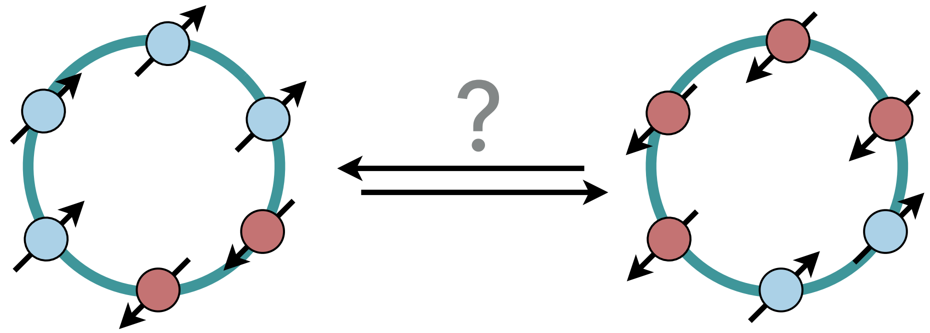

A: only when $c = 0$

$$E(a,b,c) = a\sum_{i=1}^{N} S_i\, S_{i+1} + b\sum_{i=1}^{N} S_i\, S_{i+2} + c\sum_{i=1}^{N} S_i$$

WARM UP QUESTION

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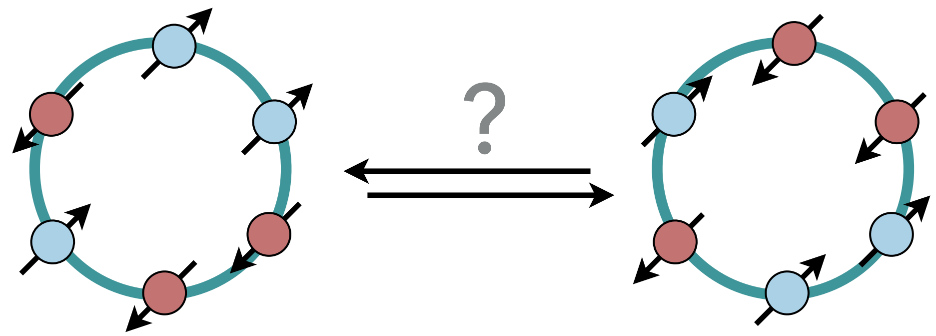
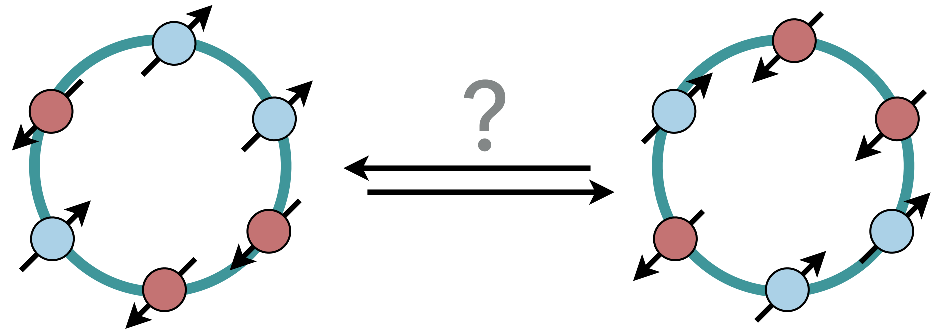


$$E(a,b,c) = a \sum_{i=1}^{N} S_i\, S_{i+1} + b \sum_{i=1}^{N} S_i\, S_{i+2} + c \sum_{i=1}^{N} S_i$$

WARM UP QUESTION

Q: are these two states always degenerate for all values of a, b, c*?*



A: yes, because $\sum_i S_i = 0$

$$E(a,b,c) = a\sum_{i=1}^{N} S_i\, S_{i+1} + b\sum_{i=1}^{N} S_i\, S_{i+2} + c\sum_{i=1}^{N} S_i$$

EXERCISE #1

Write a function for the energy of N spins in a loop, as a function a, b, c.

$$\boxed{E(a,b,c) = a\sum_{i=1}^{N} S_i\, S_{i+1} + b\sum_{i=1}^{N} S_i\, S_{i+2} + c\sum_{i=1}^{N} S_i}$$

look inside my code 😎

```python
def rotate_vec(vec0):
    """
    this piece of code rotates an array (vec0)
    by one to the left
    """
    N=len(vec0)
    tmp = np.zeros(N)

    tmp[0:N-1]=vec0[1:N]
    tmp[N-1]=vec0[0]

    return tmp


def Eising(St,a,b,c):
    "rotate the spins by one"
    Stp1 = rotate_vec(St)
    "rotate the spins by two"
    Stp2 = rotate_vec(Stp1)

    "nearest neighbors"
    dEa = a * sum(St * Stp1)
    "next-to-nearest neighbors"
    dEb = b * sum(St * Stp2)
    "background field"
    dEc = c * sum(St)

    return dEa + dEb + dEc
```

EXERCISE #2

Write code to list all possible configurations for N spins.

```
def ising_lists(N):
    """
    if we N possible spins,
    we have 2^N possible states

    we will put these into lists,
    starting with a single spin that is
    either up or down
    """
    TOT=[[1],[-1]]

    for n in range(N-1):

        "tmp0 is a place holder for some of the states"

        Nt = len(TOT)
        for j0 in range(Nt):
            state1 = TOT[j0][:]
            state2 = TOT[j0][:]

            "we add 1 to the first one"
            state1.append(1)
            "we add -1 to the first one"
            state2.append(-1)

            TOT[j0]=state1
            TOT.append(state2)


    return TOT
```

look inside my code 😎

EXERCISE #3-6

Find the ***ground state energy*** and ***degeneracy*** for the following values of the parameters.

<u>Exercise #3:</u> $N = 3,\ a = 5,\ b = 1,\ c = 0.01$

<u>Exercise #4:</u> $N = 10,\ a = -5,\ b = 1,\ c = 0$

<u>Exercise #5:</u> $N = 10,\ a = -5,\ b = 1,\ c = 0.01$

<u>Exercise #6:</u> $N = 10,\ a = -5,\ b = 1,\ c = -0.01$

how do we make sense of these three results?

<u>Exercise #7:</u> $N = 15,\ a = 15,\ b = -0.2,\ c = 0.02$

EXERCISE #8

Consider a system with N=10 spins. This can have $2^{10} = 1{,}024$ distinct states.

Consider $a = 1, b = 0.1$.

Q1: What is(are) the ground state(s) when $c = 0$ and its energy?

Q2: What is(are) the ground state(s) when $c = -\infty$ and its energy?

$$E(a,b,c) = a \sum_{i=1}^{N} S_i \, S_{i+1} + b \sum_{i=1}^{N} S_i \, S_{i+2} + c \sum_{i=1}^{N} S_i$$

EXERCISE #8

Consider a system with N=10 spins. This can have $2^{10} = 1{,}024$ distinct states.

Consider $a = 1, b = 0.1$.

Q1: What is(are) the ground state(s) when $c = 0$ and its energy?

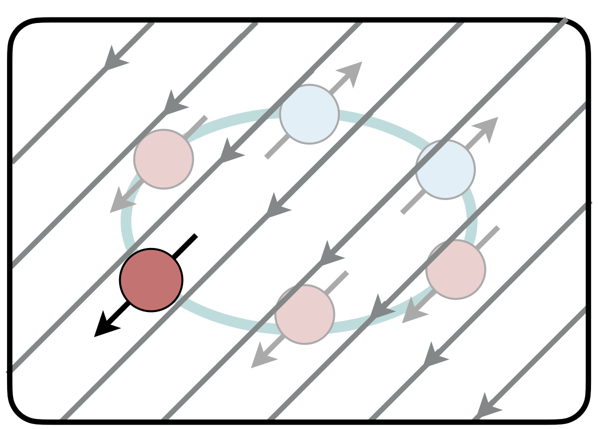
$$(\uparrow, \downarrow, \uparrow, \downarrow, \uparrow, \downarrow, \uparrow, \downarrow, \uparrow, \downarrow)$$
$$(\downarrow, \uparrow, \downarrow, \uparrow, \downarrow, \uparrow, \downarrow, \uparrow, \downarrow, \uparrow)$$

check numerically and find the energy of the system

Q2: What is(are) the ground state(s) when $c = -\infty$ and its energy?

$$(\uparrow, \uparrow, \uparrow, \uparrow, \uparrow, \uparrow, \uparrow, \uparrow, \uparrow, \uparrow)$$

check numerically by making c increasingly large and negative.



makes sense, the stronger the background field, the more the spins wants to align with it…

$$E(a,b,c) = a\sum_{i=1}^{N} S_i\,S_{i+1} + b\sum_{i=1}^{N} S_i\,S_{i+2} + c\sum_{i=1}^{N} S_i$$

EXERCISE #8

Consider a system with N=10 spins. This can have $2^{10} = 1{,}024$ distinct states.

Consider $a = 1, b = 0.1$.

Vary c continuously from *0* to *-3*.

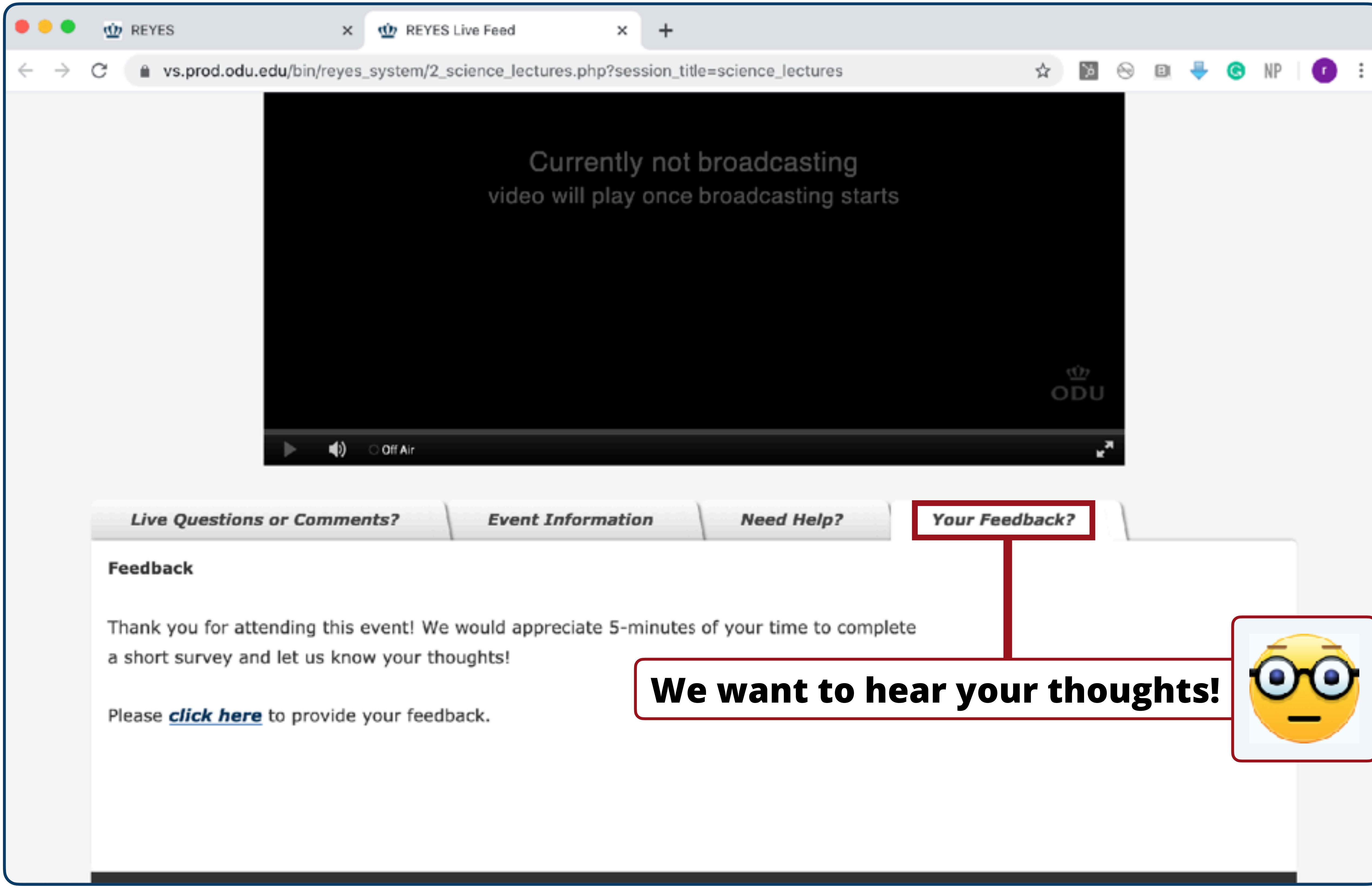
Q3: At what value of c are these no longer the ground state?

$$\boxed{\begin{array}{c}(\uparrow,\downarrow,\uparrow,\downarrow,\uparrow,\downarrow,\uparrow,\downarrow,\uparrow,\downarrow) \\ (\downarrow,\uparrow,\downarrow,\uparrow,\downarrow,\uparrow,\downarrow,\uparrow,\downarrow,\uparrow)\end{array}}$$

Q4: At what value of c is this the ground state? [note, these two do not have have to be the same values for c]

$$\boxed{(\uparrow,\uparrow,\uparrow,\uparrow,\uparrow,\uparrow,\uparrow,\uparrow,\uparrow,\uparrow)}$$

VIDEO STREAMS // VS.PROD.ODU.EDU/BIN/REYES_SYSTEM/



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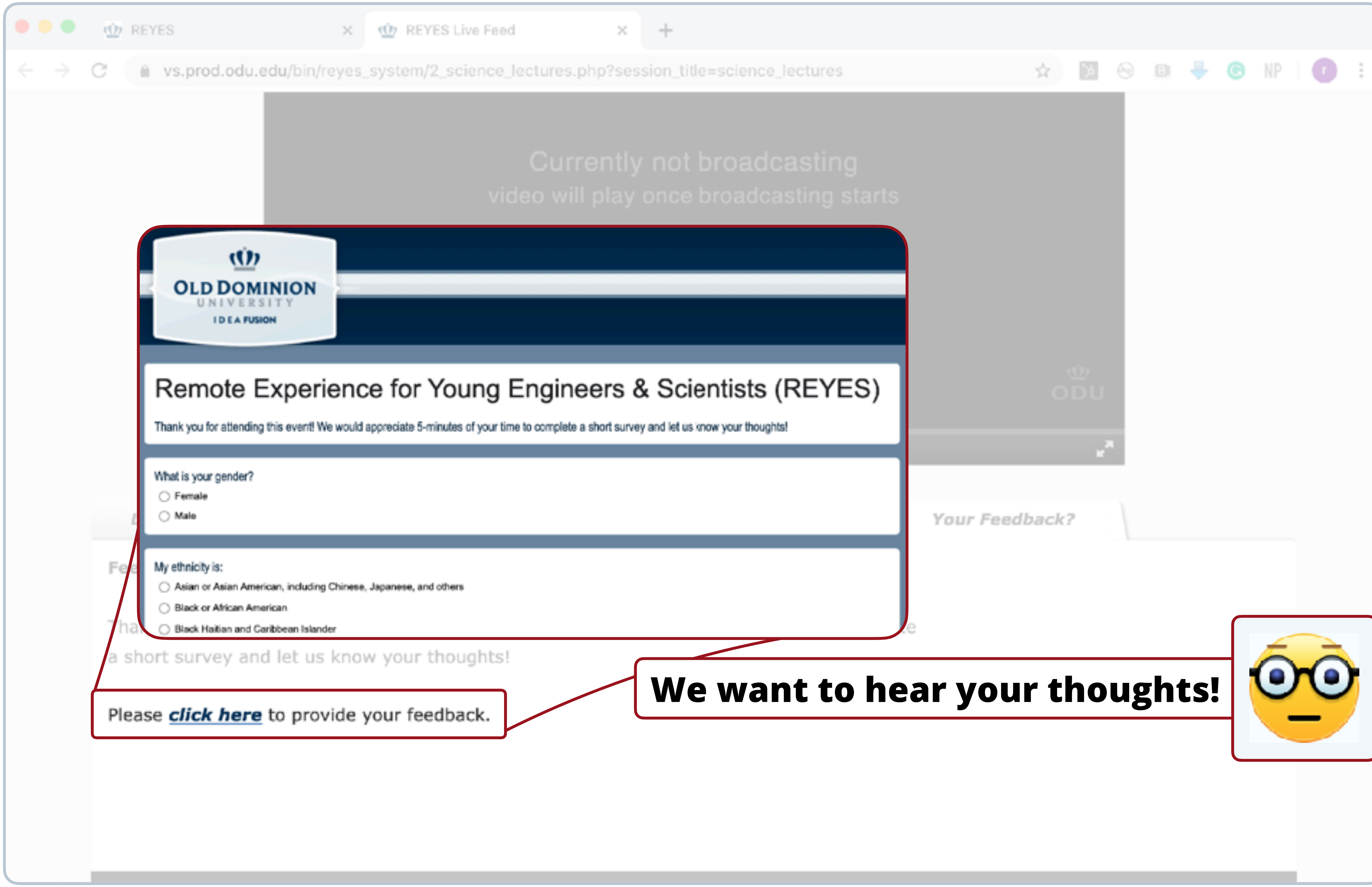

POTENTIAL PROJECTS

Next week we will introduce numerical limit, which will allow us to introduce derivatives. Also, we might introduce discrete Fourier transforms.

Neither one of these will require you having taken calculation.

We will be creating projects from there…