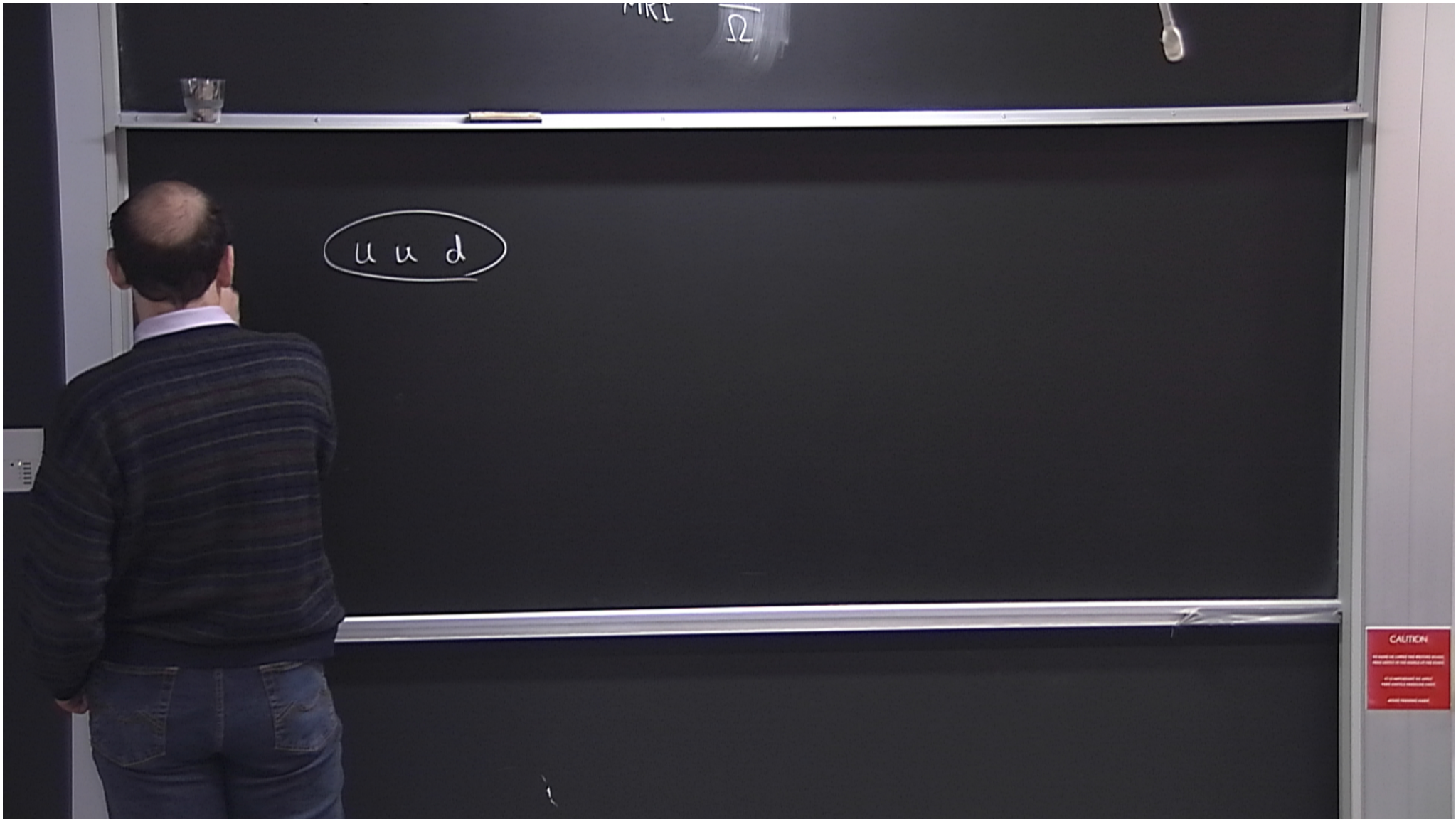


Title: PHYS 781 - Lecture 22

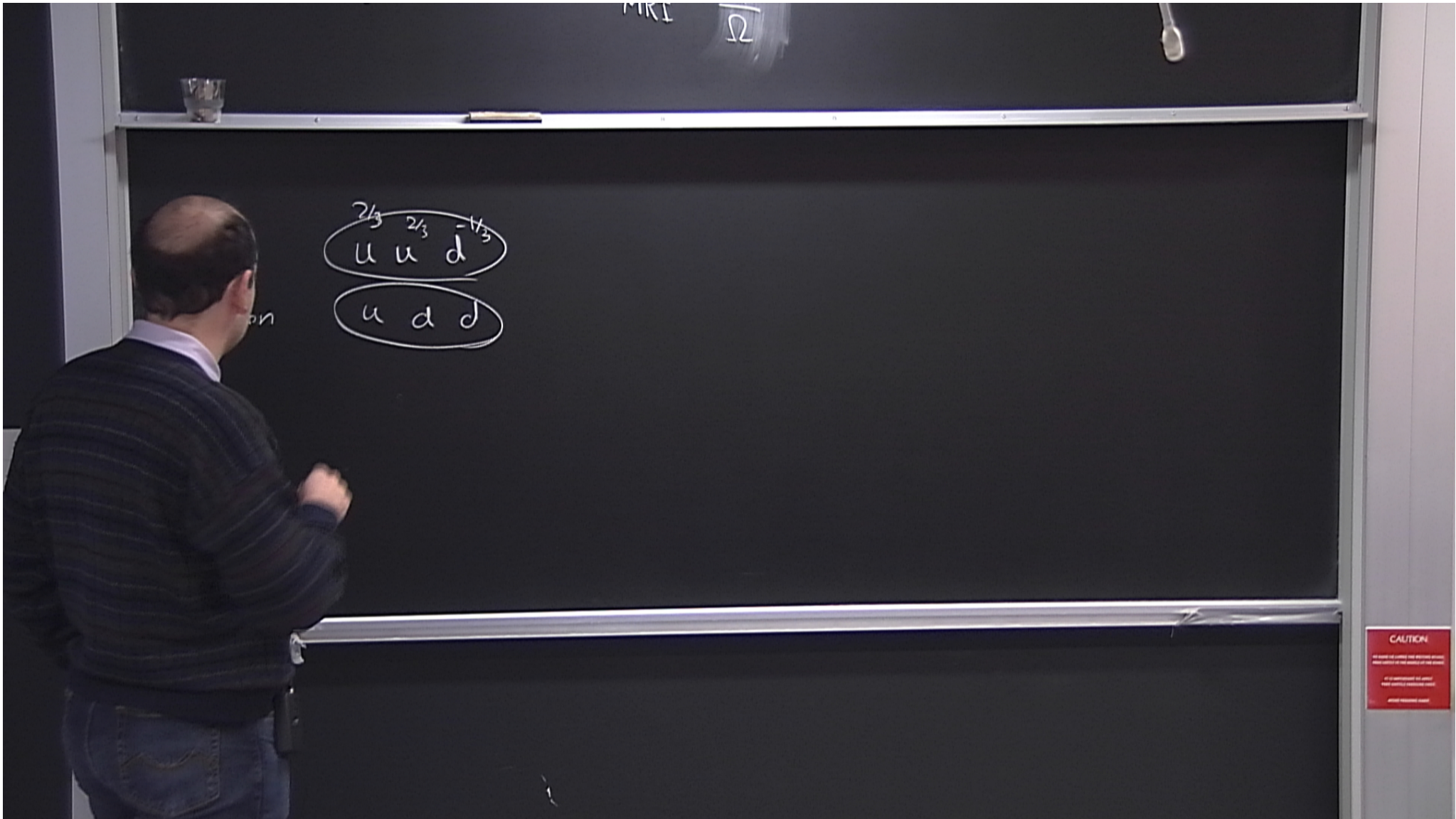
Date: Nov 21, 2014 12:00 PM

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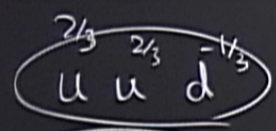
Abstract:



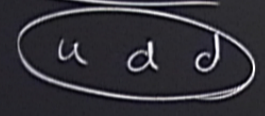




proton



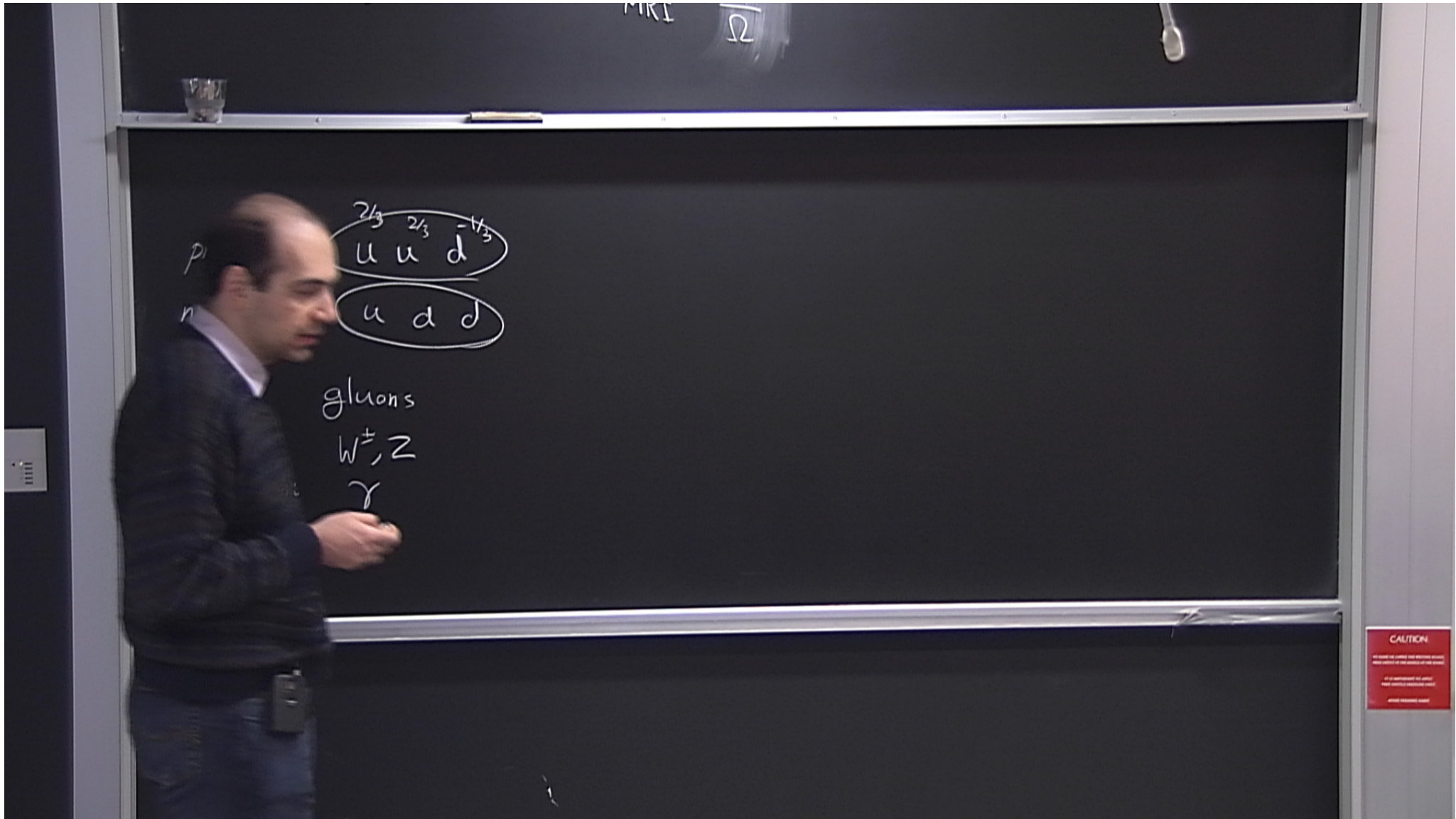
neutron



MKI  $\Omega$







MRI  $\Omega$

proton  $\begin{matrix} 2/3 & 2/3 & -1/3 \\ u & u & d \end{matrix}$

neutron  $\begin{matrix} u & d & d \end{matrix}$

Strong: gluons  
Weak:  $W^\pm, Z$   
electromag:  $\gamma$   
gravity: graviton

CAUTION  
BE CAREFUL OF CABLES AND WIRING BEHIND THIS WALL IN THE AREA OF THE ROOM.  
DO NOT ATTEMPT TO UNPLUG OR REPAIR WIRING BEHIND THIS WALL.  
AVOID PHYSICAL CONTACT.



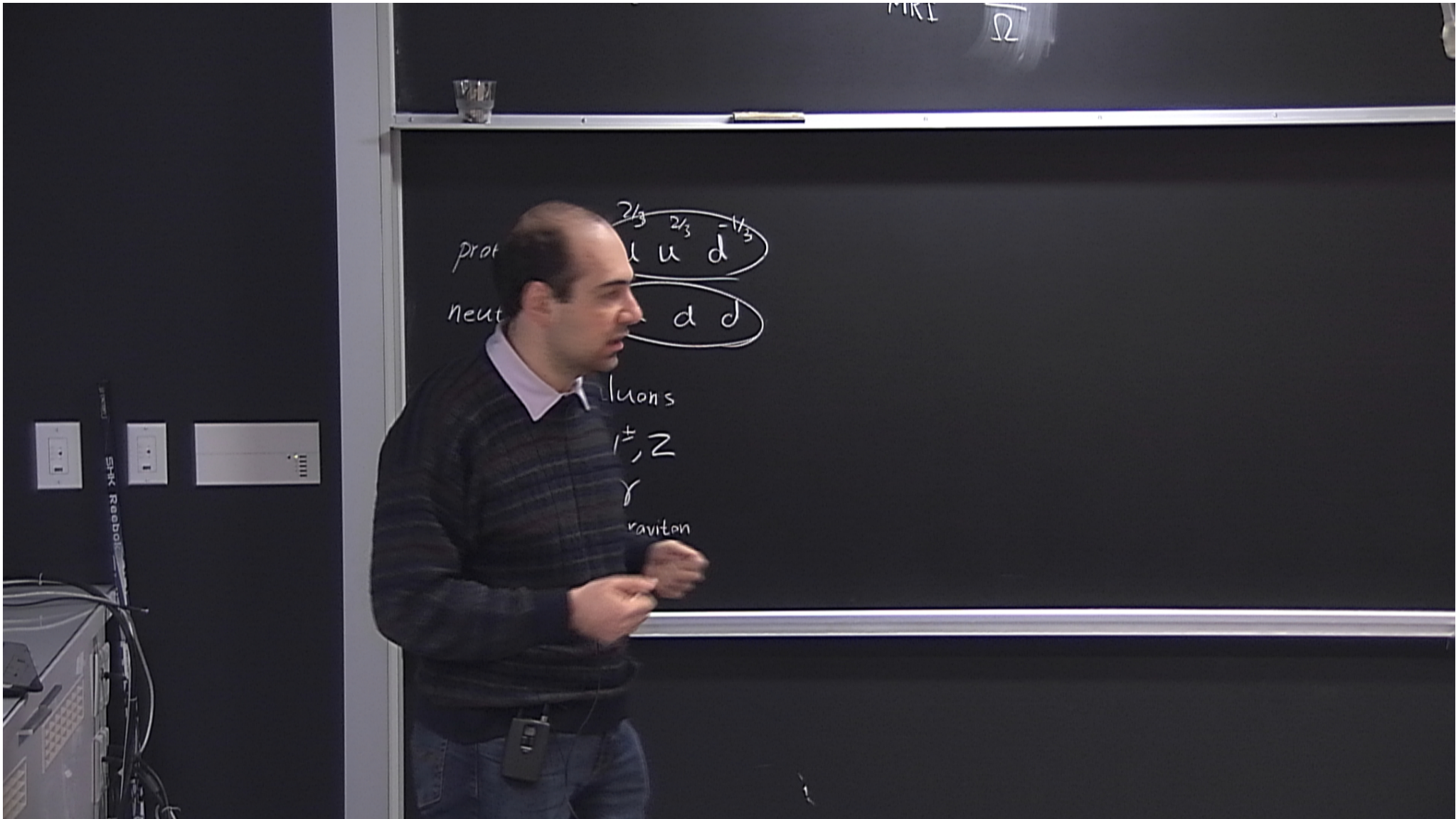
MRI  $\Omega$

proton  $\begin{matrix} 2/3 & 2/3 & -1/3 \\ u & u & d \end{matrix}$

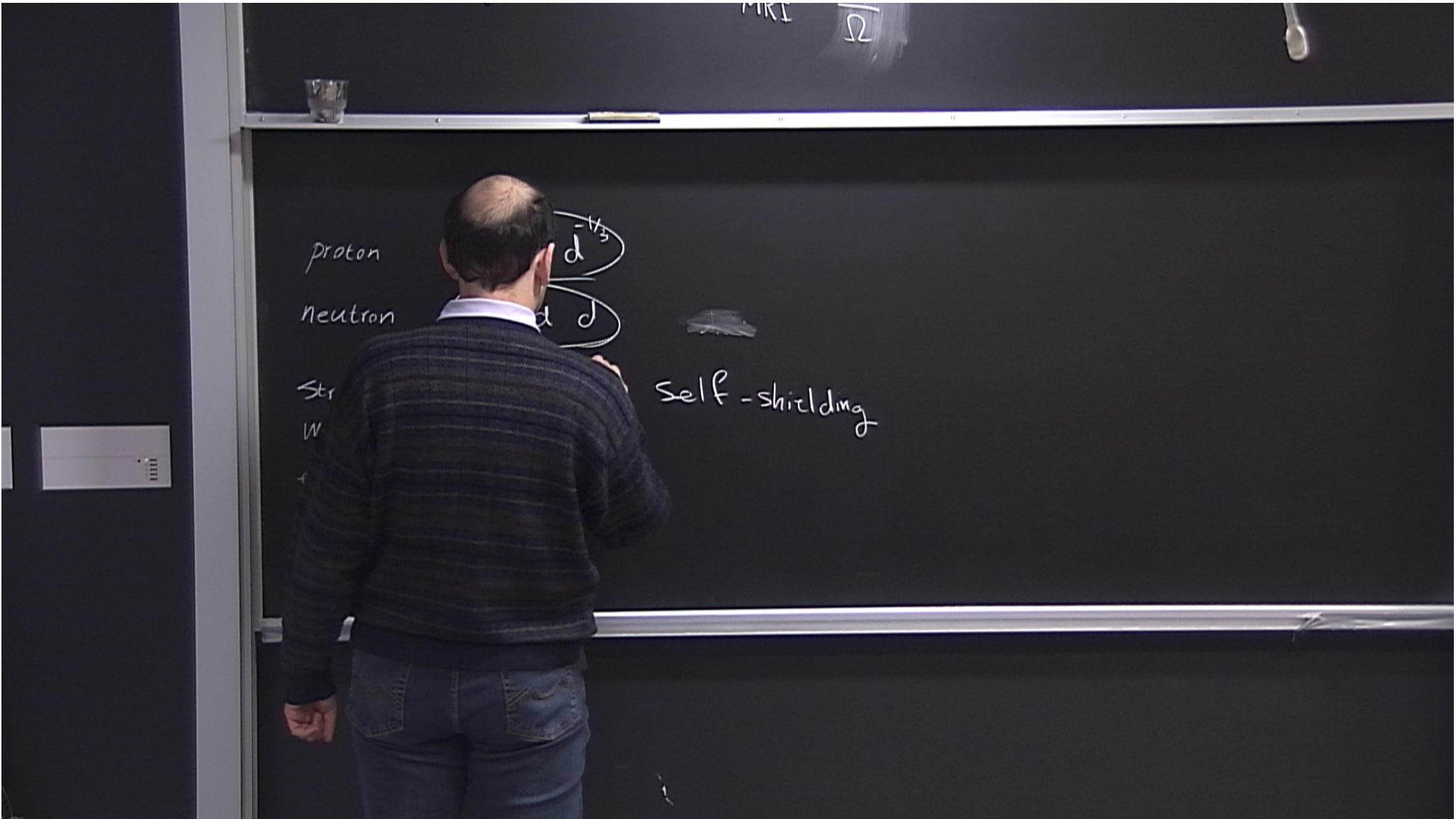
neutron  $\begin{matrix} u & d & d \end{matrix}$

Strong: gluons  
Weak:  $W^\pm, Z$   
electromag:  $\gamma$   
gravity: graviton

CAUTION  
DO NOT TOUCH THE WALLS OR CEILING OF THE ROOM  
IF IT IS NECESSARY TO LEAVE  
PLEASE CONTACT THE STAFF

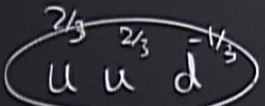






MRI  $\Omega$

proton



neutron



Strong:

gluons  $\xrightarrow{\text{Short Range}}$  self-shielding

Weak:

$W^\pm, Z \xrightarrow{\text{Short Range}}$  massive gauge bosons

electromag:

$\gamma$

gravity:

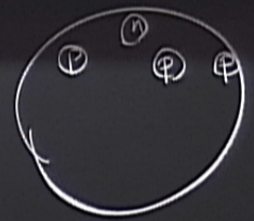
graviton



MRI  $\Omega$

nucleus

effective field theory



proton  $\begin{matrix} 2/3 & 2/3 & -1/3 \\ \hline u & u & d \end{matrix}$

neutron  $\begin{matrix} u & d & d \end{matrix}$

Strong: gluons  $\rightarrow$  Short Range

Weak:  $W^\pm, Z$   $\rightarrow$

electromag:  $\gamma$

gravity: graviton



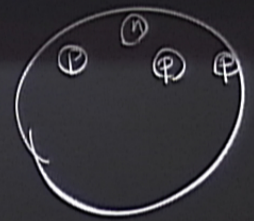
CAUTION  
DO NOT TOUCH THE WALLS OR CEILING  
IF AN EMERGENCY OCCURS  
PLEASE CONTACT THE STAFF



MRI  $\Omega$

nucleus

effective field theory



proton  $\frac{2}{3}$   $\frac{2}{3}$   $-\frac{1}{3}$   
u u d

neutron  
u d d

Strong: gluons  $\xrightarrow{\text{Short Range}}$  self-shielding  
 Weak:  $W^\pm, Z \xrightarrow{\text{Short Range}}$  massive gauge bosons  
 electromag:  $\gamma$   
 gravity: graviton

CAUTION  
 Do not touch the control panel  
 when it is in use.  
 If it is necessary to open  
 the control panel, please  
 contact the staff.

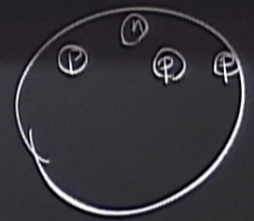


MRI  $\Omega$

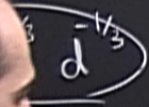
nucleus

effective field theory

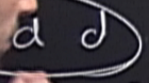
Droplet model



proton



neutron



Strong

short range

Self-shielding

Weak

massive gauge bosons

electromagnetic

gravitational

**CAUTION**  
 Do not touch the control panel  
 when it is in use.  
 If it is necessary to touch  
 the control panel, please  
 contact the staff.

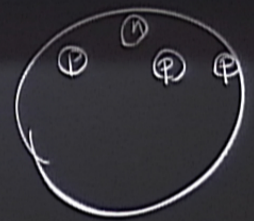


MRI  $\Omega$

nucleus

effective field theory

Droplet model



proton  $\begin{matrix} 2/3 & 2/3 & -1/3 \\ u & u & d \end{matrix}$

neutron  $\begin{matrix} u & d & d \end{matrix}$

Strong: gluons  $\xrightarrow{\text{Short Range}}$  self-shielding

Weak:  $W^\pm, Z \longrightarrow$  massive gauge bosons

electromag:  $\gamma$

gravity: graviton

$A = \# n + p$

$Z = \# p$

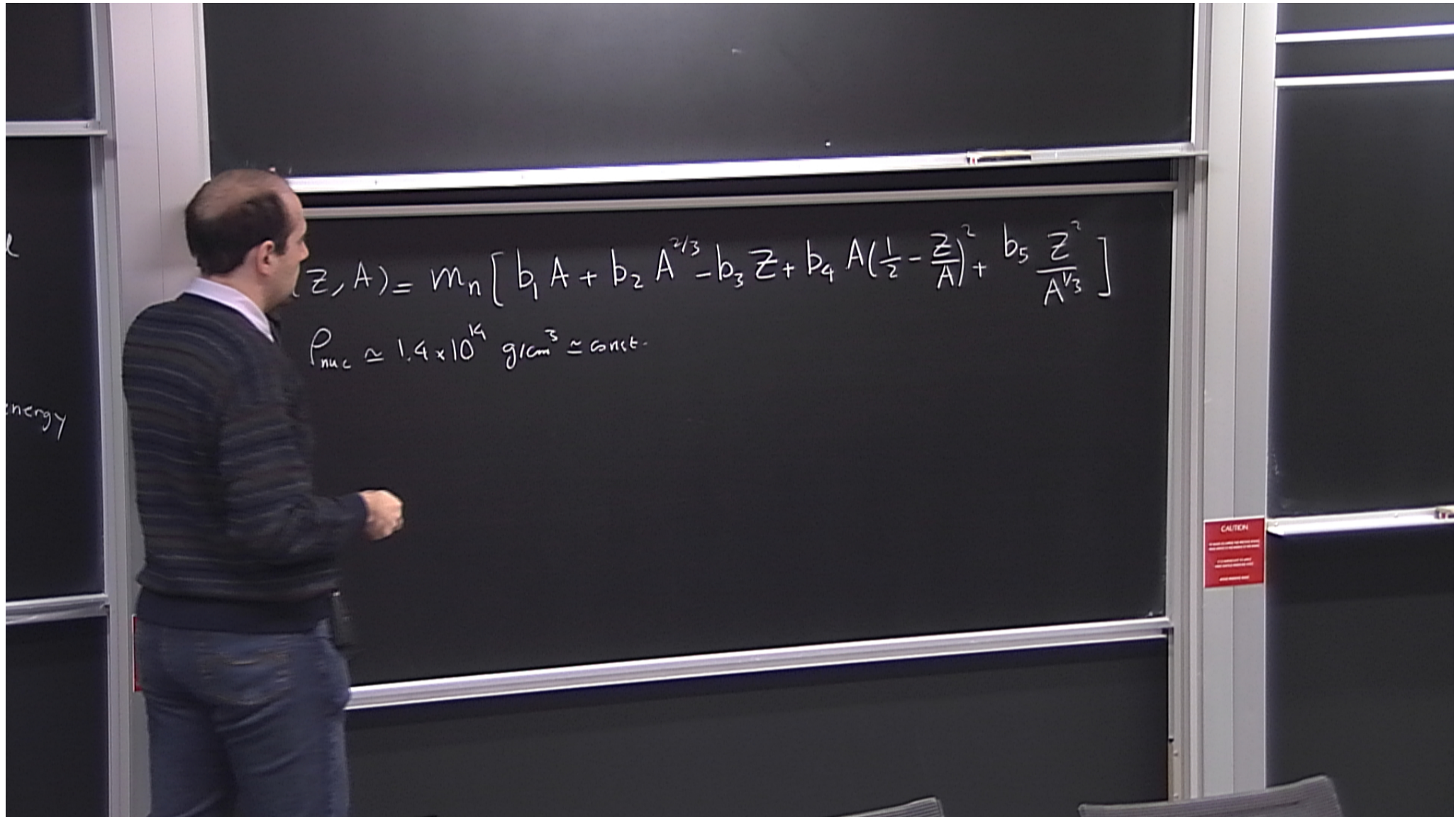
$$Mc^2 = (A-Z)m_n c^2 + Z m_p c^2 - A$$

binding energy / nucleon



$$M(z, A) = m_n \left[ b_1 A + b_2 A^{2/3} - b_3 z + b_4 \left( \frac{z}{A^{1/3}} \right)^2 + b_5 \frac{z^2}{A^{1/3}} \right]$$





$$E(Z, A) = m_n \left[ b_1 A + b_2 A^{2/3} - b_3 Z + b_4 A \left( \frac{1}{2} - \frac{Z}{A} \right)^2 + b_5 \frac{Z^2}{A^{1/3}} \right]$$

$$\rho_{nuc} \approx 1.4 \times 10^{14} \text{ g/cm}^3 \approx \text{const.}$$

energy

CAUTION



$$M(Z, A) = m_n \left[ b_1 A + b_2 A^{2/3} - b_3 Z + b_4 A^{1/2} \frac{Z^2}{A^{1/3}} \right]$$

nuclear rest mass  
 surface tension

$\rho_{nuc} \approx 1.4 \times 10^{14} \text{ g/cm}^3 \approx \text{const.}$

CAUTION

CAUTION



$$M(Z, A) = m_n \left[ b_1 A + b_2 A^{2/3} - b_3 Z + b_4 A \left( \frac{1}{2} - \frac{Z}{A} \right)^2 + b_5 \frac{Z^2}{A^{1/3}} \right]$$

$\rho_{\text{nuc}} \approx 1.4 \times 10^{14} \text{ g/cm}^3 \approx \text{const.}$

Annotations:
 

- Arrow from  $b_1 A$  to "nuclear rest mass"
- Arrow from  $b_2 A^{2/3}$  to "Surface tension"
- Arrow from  $b_4 A \left( \frac{1}{2} - \frac{Z}{A} \right)^2$  to "electrostatic"
- Arrow from  $b_5 \frac{Z^2}{A^{1/3}}$  to "electrostatic"

CAUTION

CAUTION



effective field theory

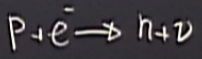
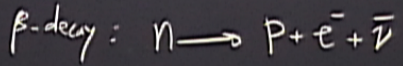
binding / nucleon  
 $Z m_p \approx A \bar{E}_b$

$$V(Z, A) = V_0 V_n \left[ D_1 A + D_2 A - D_3 Z + D_4 A \left( \frac{Z}{A} - \frac{Z}{A} \right) + D_5 \frac{Z}{A^{2/3}} \right]$$

$$\rho_{nuc} \approx 1.4 \times 10^{14} \text{ g/cm}^3 \approx \text{const.}$$

Surface tension

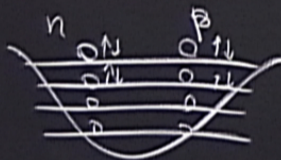
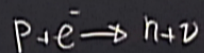
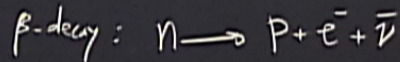
electrostatic





$$M(Z, A) = m_n \left[ b_1 A + b_2 A^{2/3} - b_3 Z + b_4 A \left( \frac{1}{2} - \frac{Z}{A} \right)^2 + b_5 Z^2 \right]$$

$$\rho_{\text{nuc}} \approx 1.4 \times 10^{14} \text{ g/cm}^3 \approx \text{const.}$$

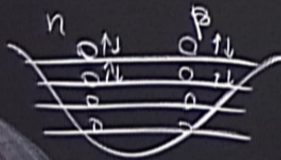
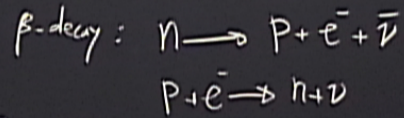




$$M(Z, A) = m_n \left[ \overset{\text{nuclear rest mass}}{b_1 A + b_2 A^{2/3}} - b_3 Z + b_4 A \left( \frac{1}{2} - \frac{Z}{A} \right)^2 + b_5 \frac{Z^2}{A^{1/3}} \right]$$

$\rho_{\text{nuc}} \approx 1.4 \times 10^{14} \text{ g/cm}^3 \approx \text{const.}$

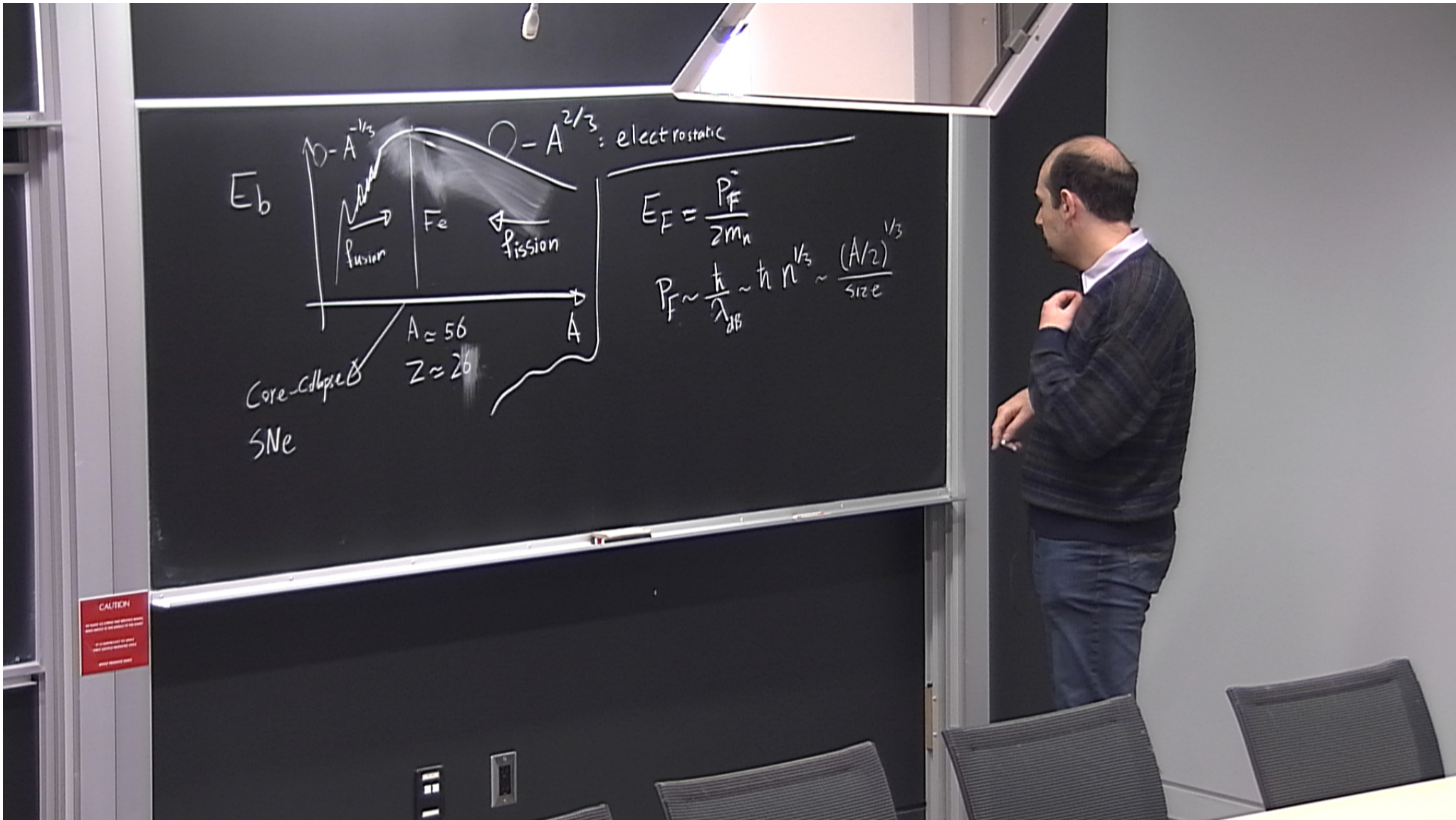
Surface tension      electrostatic



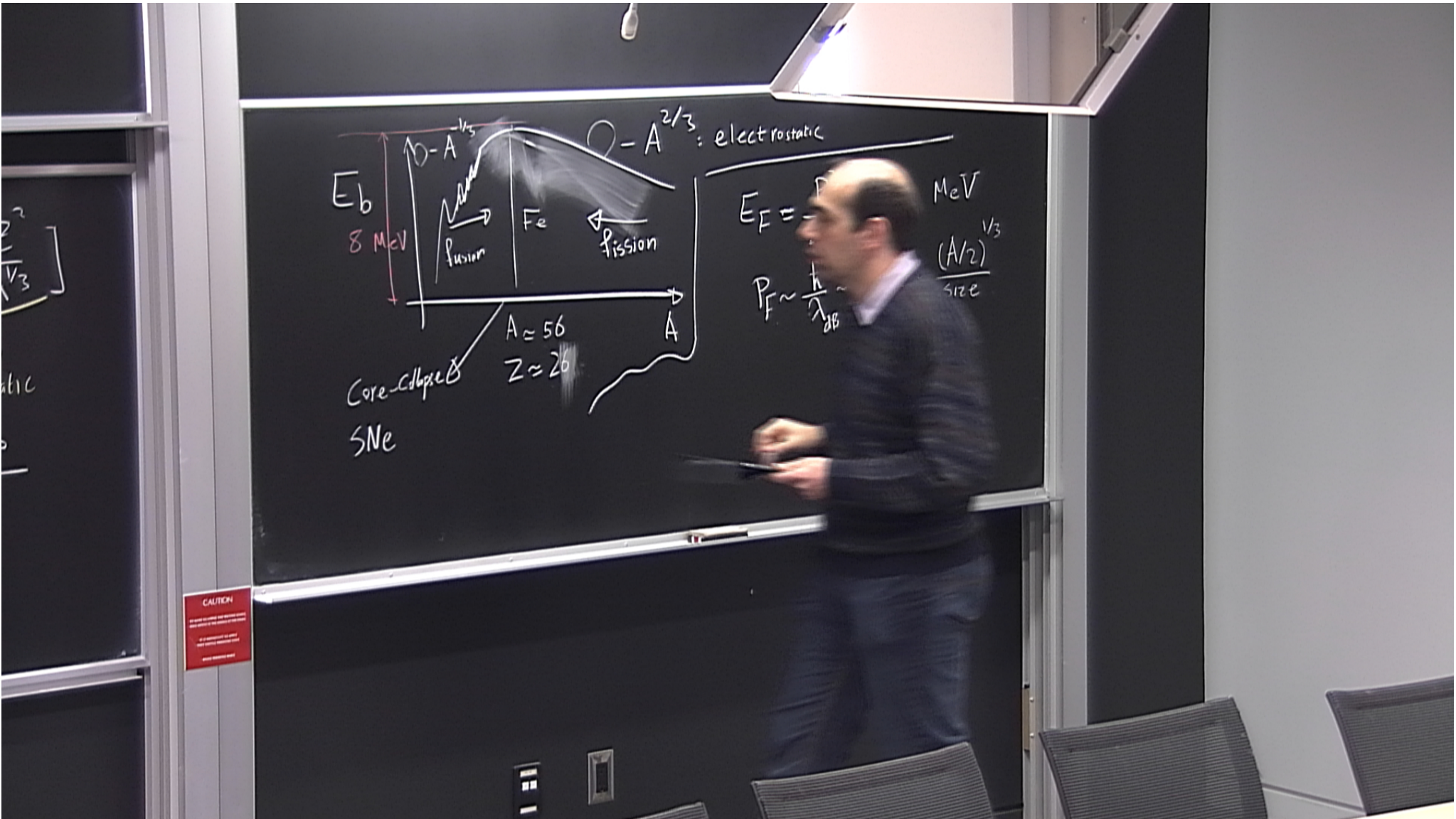




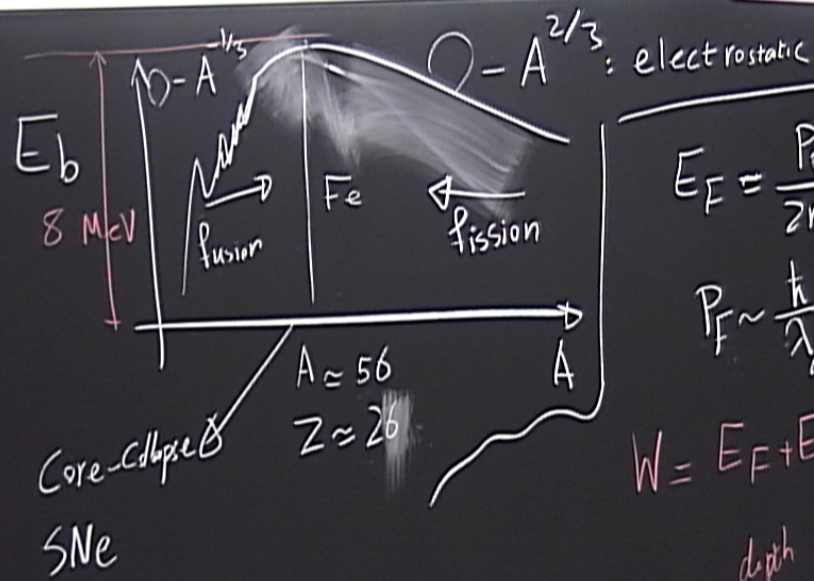












$$E_F = \frac{P_F}{2m_n} \approx 25 \text{ MeV}$$

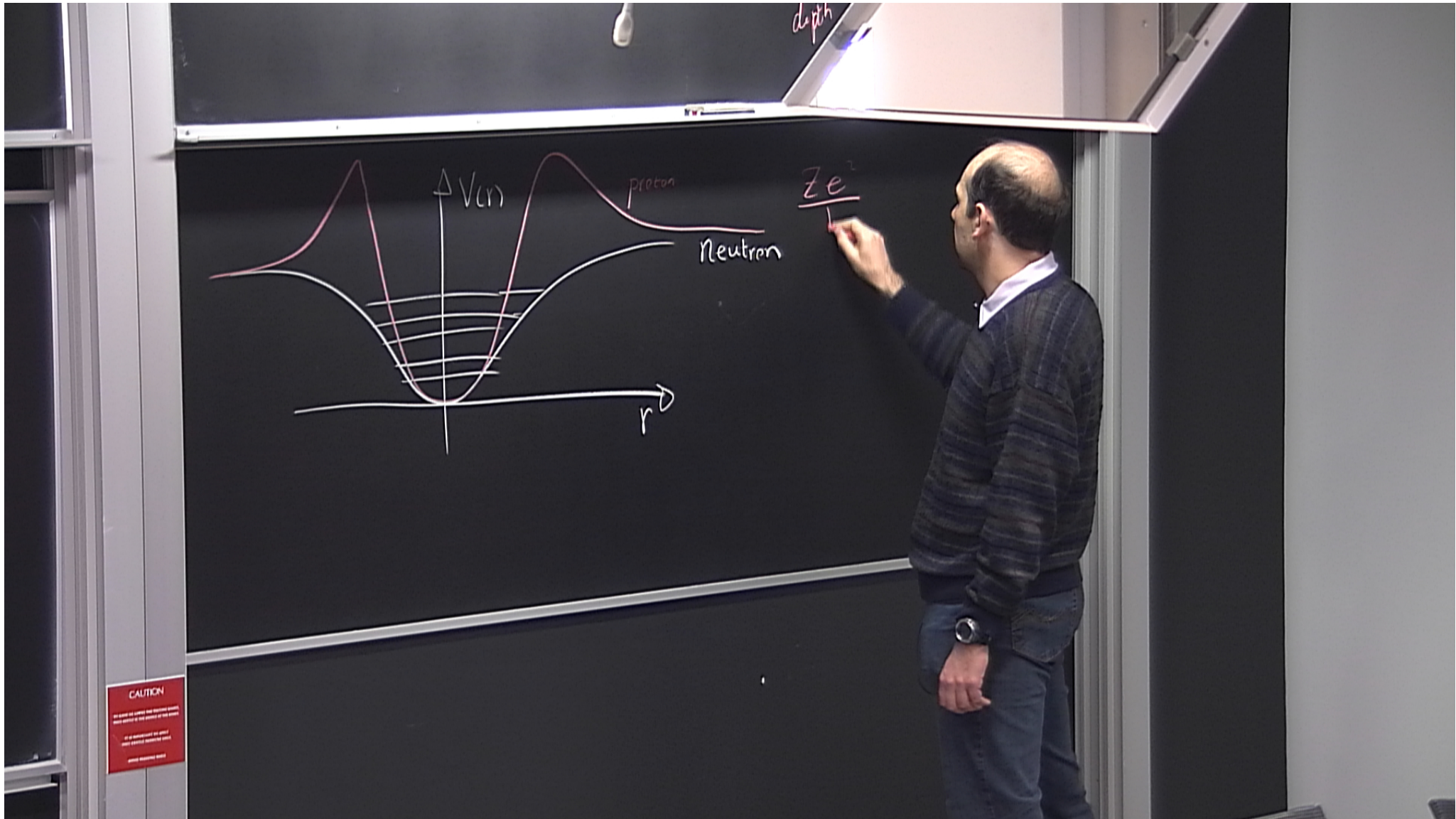
$$P_F \sim \frac{h}{\lambda_{dB}} \sim h n^{1/3} \sim \frac{(A/2)^{1/3}}{\text{size}}$$

$$W = E_F + E_b \sim 33 \text{ MeV}$$

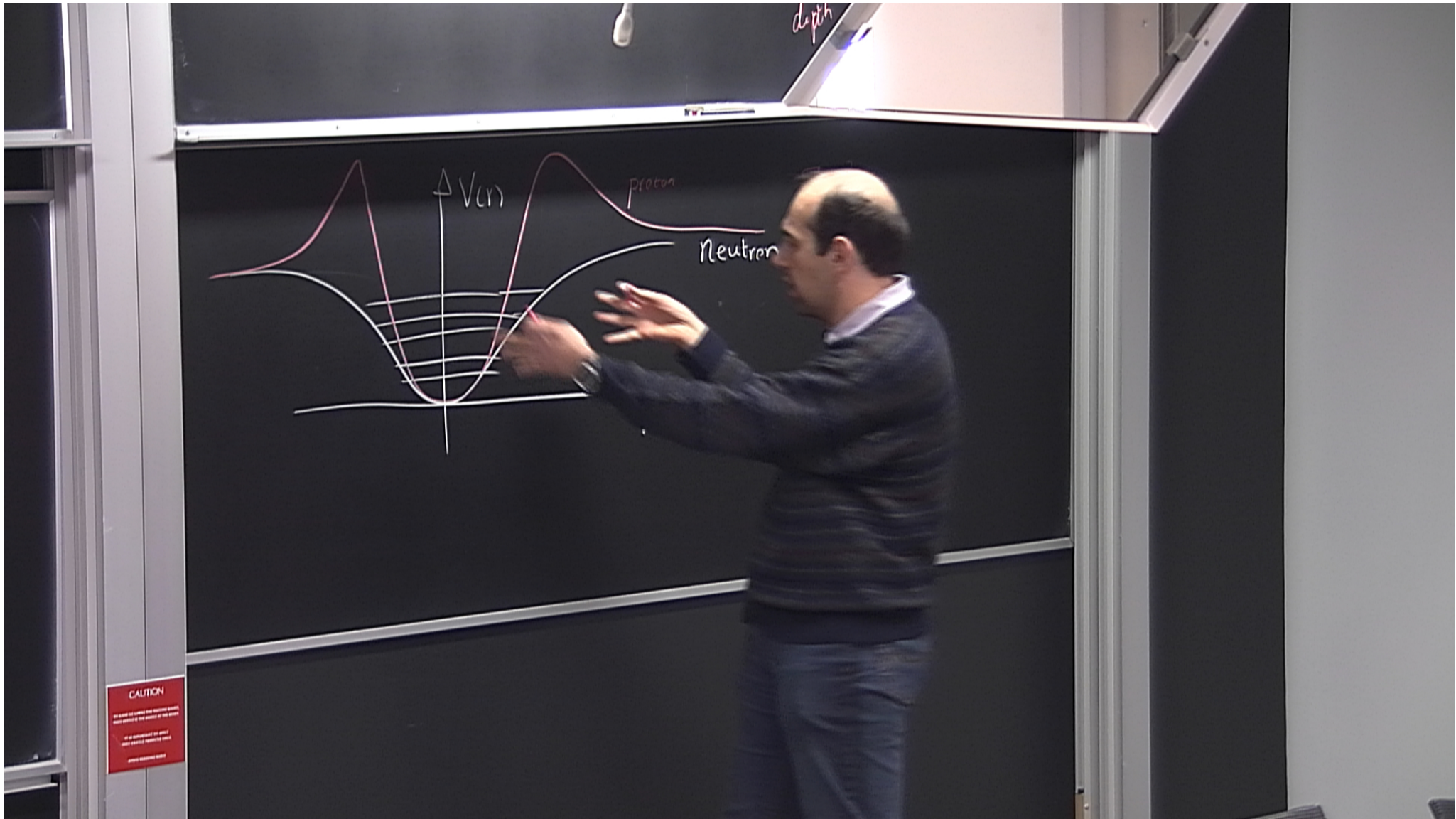
depth of typical nucleus' potential

CAUTION  
 DO NOT TOUCH THE BOARD OR THE BOARDER  
 IF IT IS NECESSARY TO Wipe  
 THE BOARD PLEASE USE THE  
 WHITE BOARD MARKER

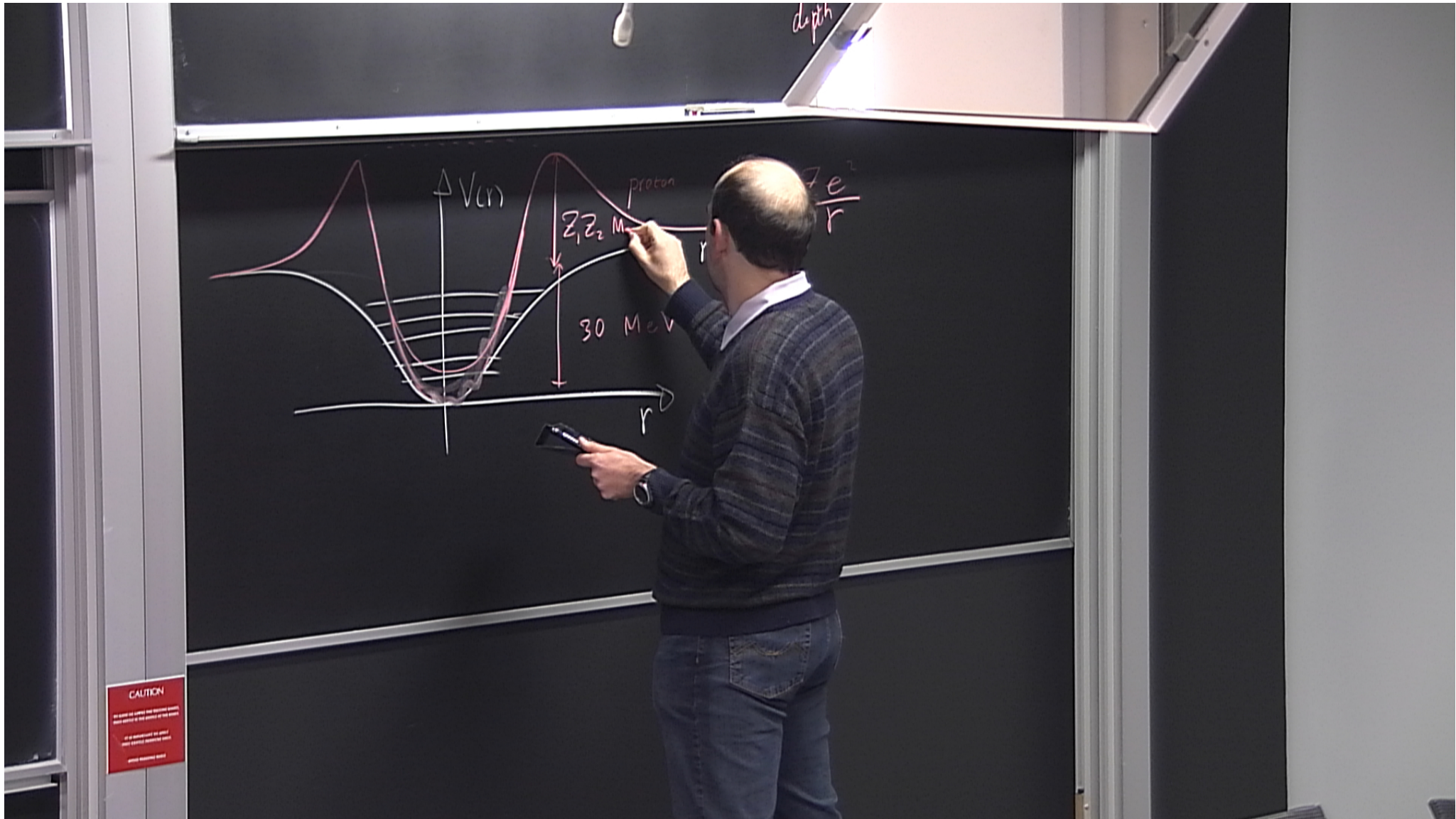




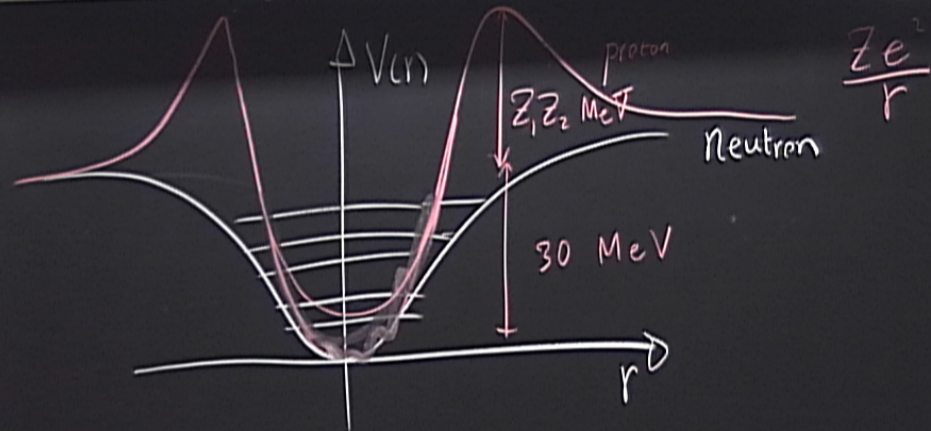








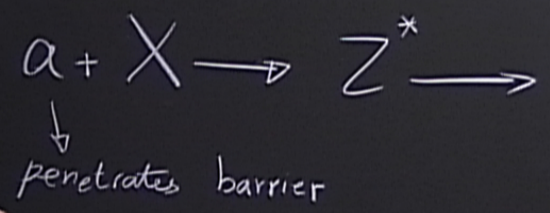




CAUTION  
 ALL OPERATIONS SHOULD BE PERFORMED UNDER  
 THE SUPERVISION OF A QUALIFIED PERSON  
 IF IN DOUBT DO NOT  
 OPERATE EQUIPMENT  
 ALWAYS WEAR SAFETY GOGGLES

$$\hbar \omega_{MRI} \sim \Omega \rightarrow L_{MRI} \sim \frac{V_A}{\Omega}$$

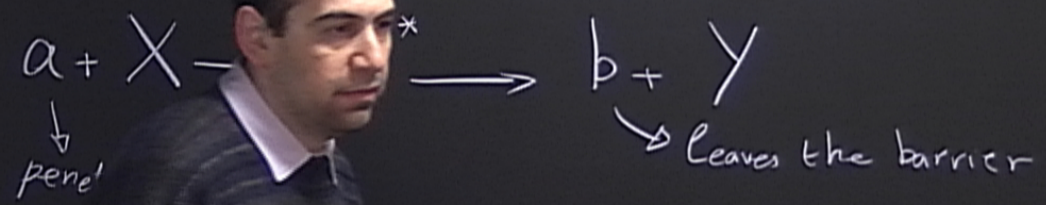
### Typical nuclear reaction





$$L_{MRI} \frac{V_A}{A} \sim \Omega \rightarrow L_{MRI} \sim \frac{V_A}{\Omega}$$

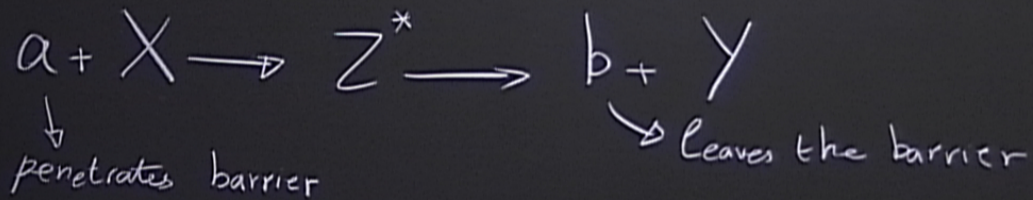
Total nuclear reaction



$$R = \frac{dN}{dt} = n_a n_x \langle \sigma v \rangle_{ab}$$

$$r_{MRI} \propto A \sim \Omega \rightarrow L_{MRI} \sim \frac{V_A}{\Omega}$$

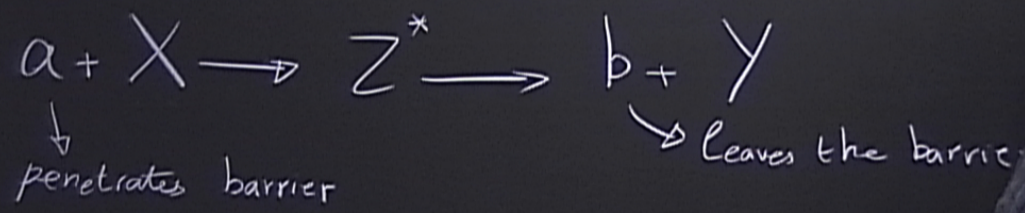
### Typical nuclear reaction



Reaction rate:  $\frac{d\#}{dt dV} = n_a n_x \langle \sigma v \rangle_{ab}$



Typical nuclear reaction

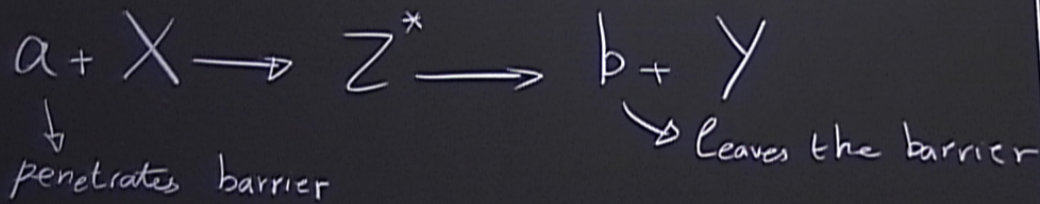


Reaction rate:  $\frac{dN}{dt dV} \equiv n_a n_x \langle \sigma v \rangle$

$$\left( \frac{8}{\pi m} \right)^{1/2} \int_0^\infty \sigma_{ab}(E) v^2 P(E) dE$$



Typical nuclear reaction



Reaction rate:  $\frac{dN}{dt dV} \equiv n_a n_x \langle \sigma v \rangle_{ab}$

$$\langle \sigma v \rangle_a = \left(\frac{8}{\pi m}\right)^{1/2} T^{-3/2} \int \sigma_{ab}(E) e^{-E/T} E dE$$

