

The Universe at the Infinitely Small Scale: **THE STANDARD MODEL**

Davide Maria Tagliabue

MILANO - POLITALKS 2024

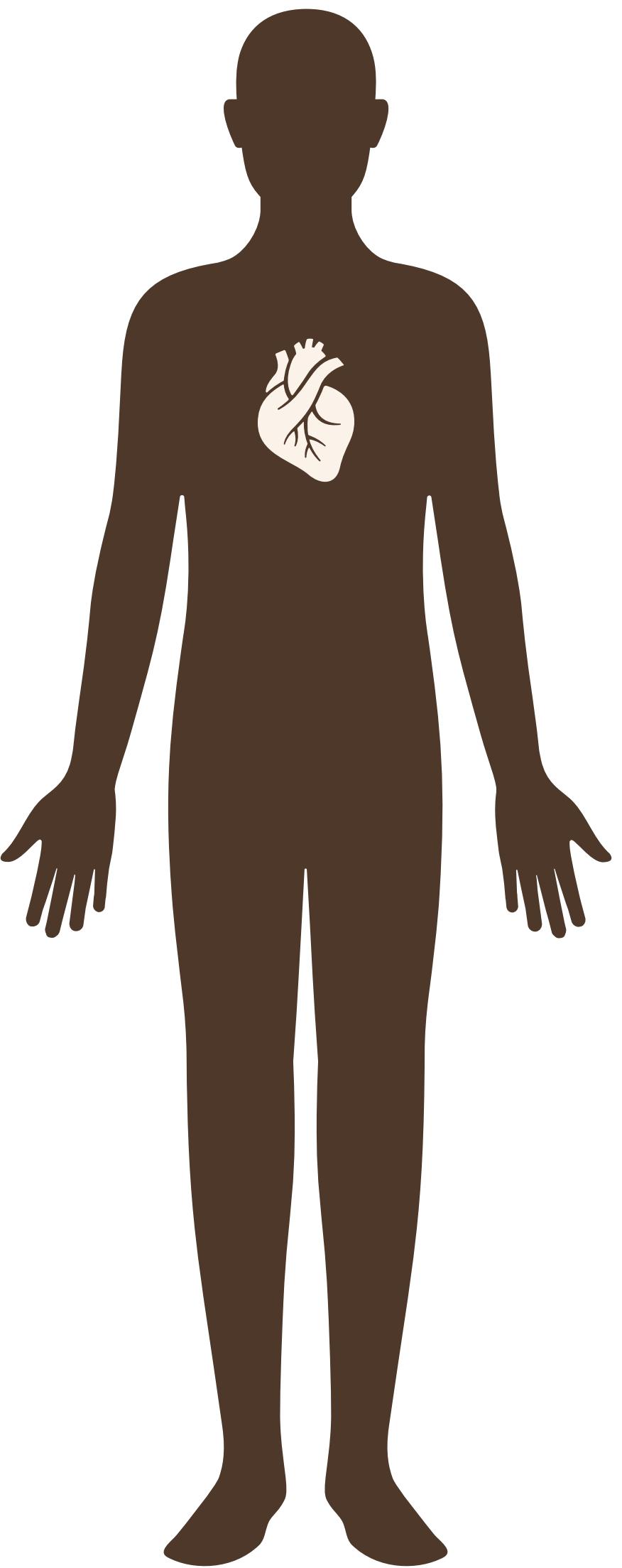


UNIVERSITÀ
DEGLI STUDI
DI MILANO

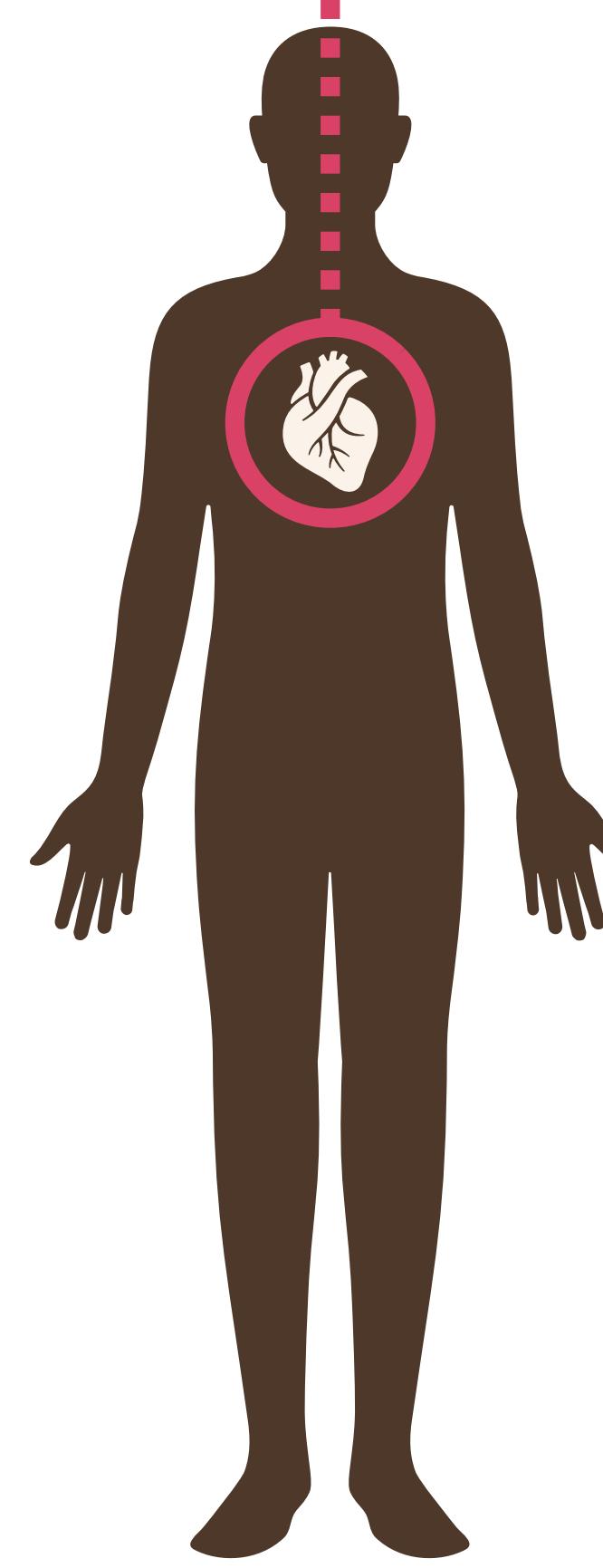
GENERAL RELATIVITY

STANDARD MODEL

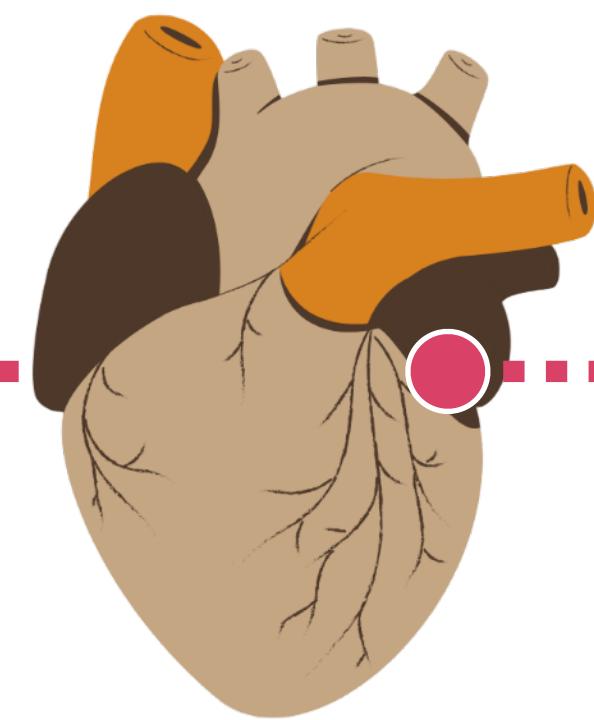
THE MATTER



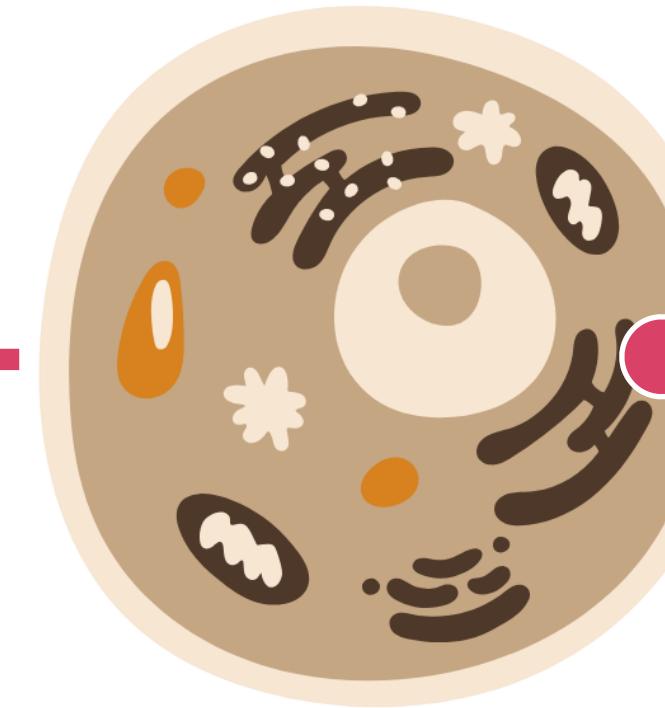
Human Body
 $(\sim 1 \text{ m})$



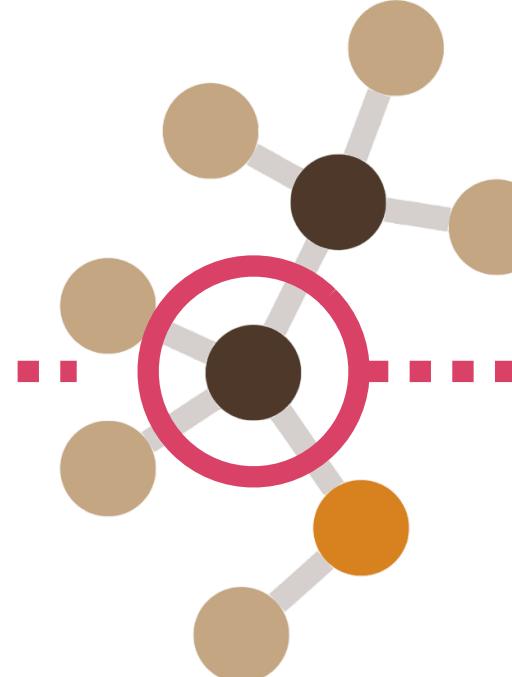
Human Body
(~ 1 m)



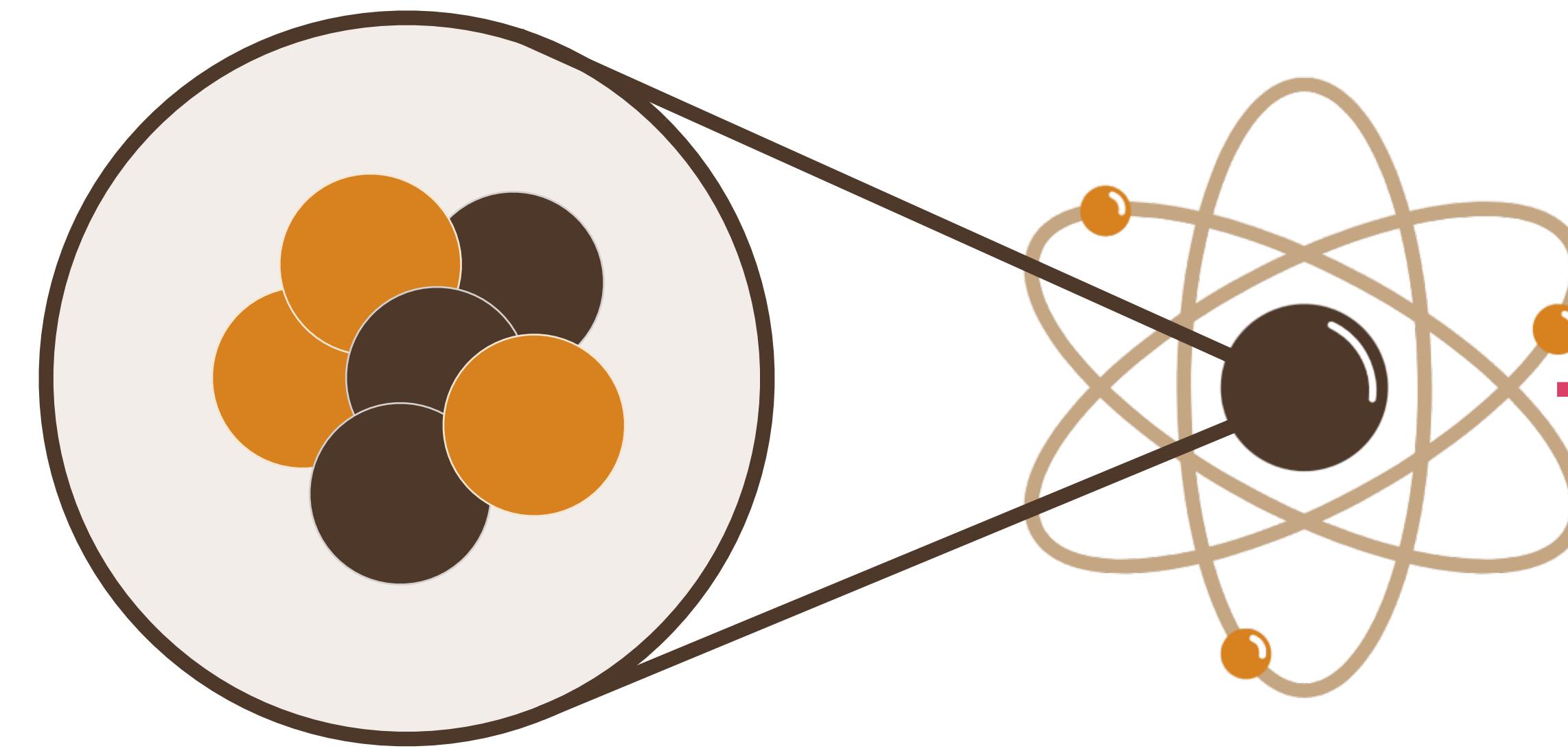
Organ
($\sim 10^{-1}$ m)



Cell
($\sim 10^{-5}$ m)



Molecule
($\sim 10^{-9}$ m)

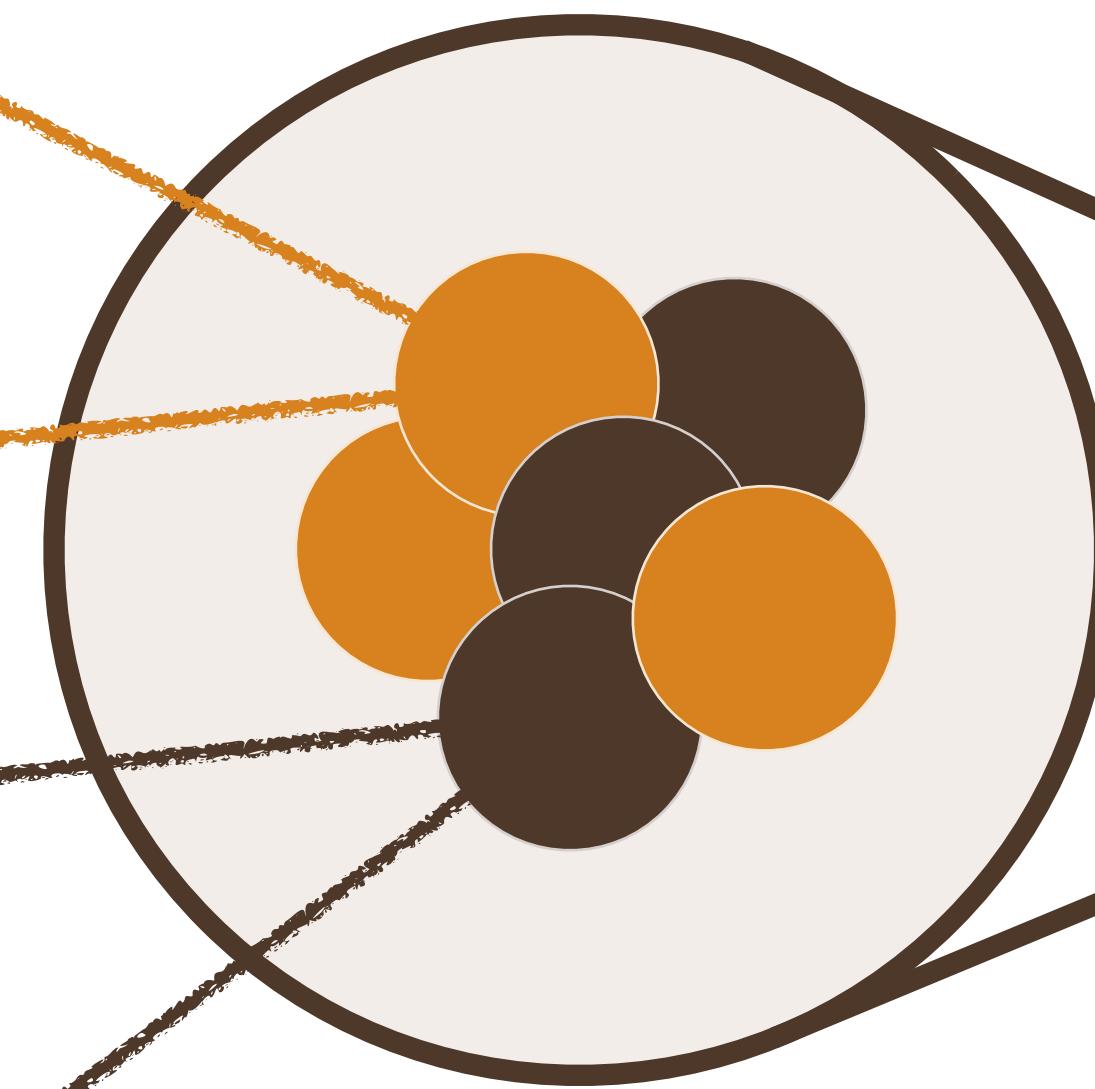
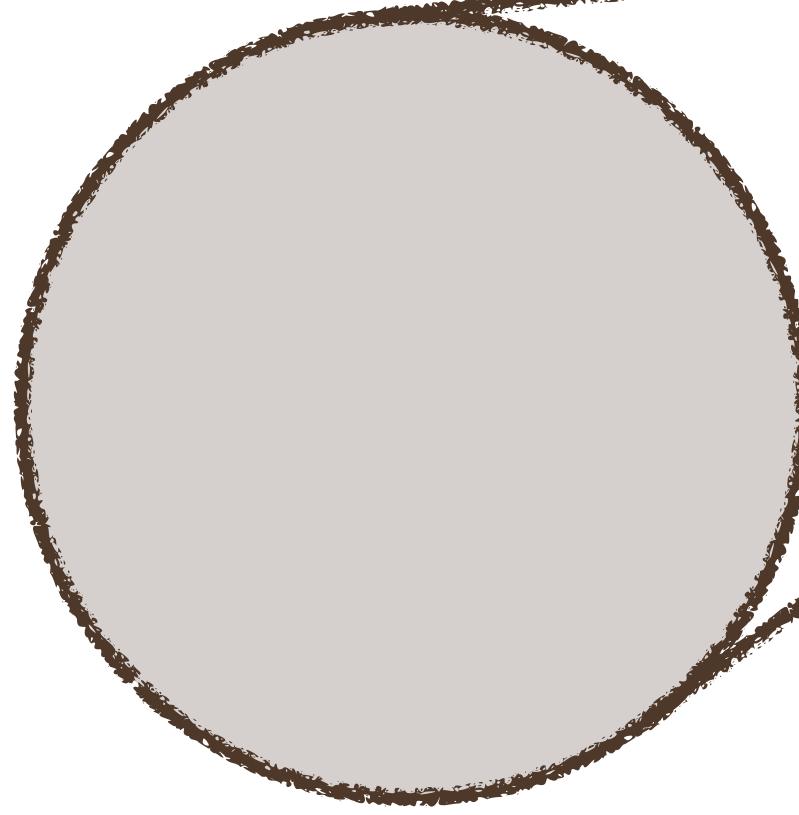
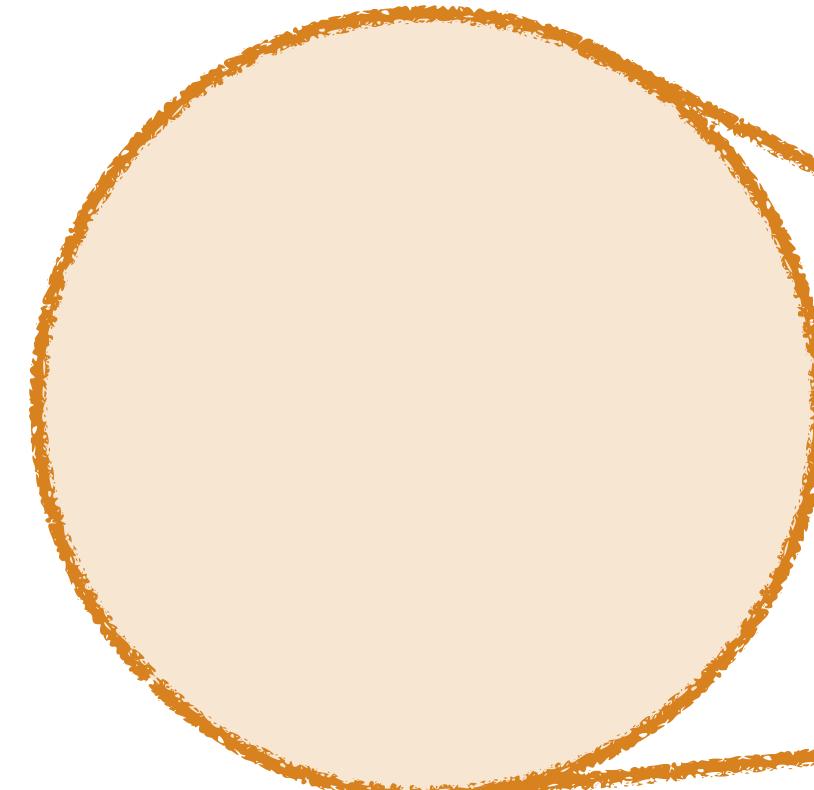


Nucleus
($\sim 10^{-15}$ m)

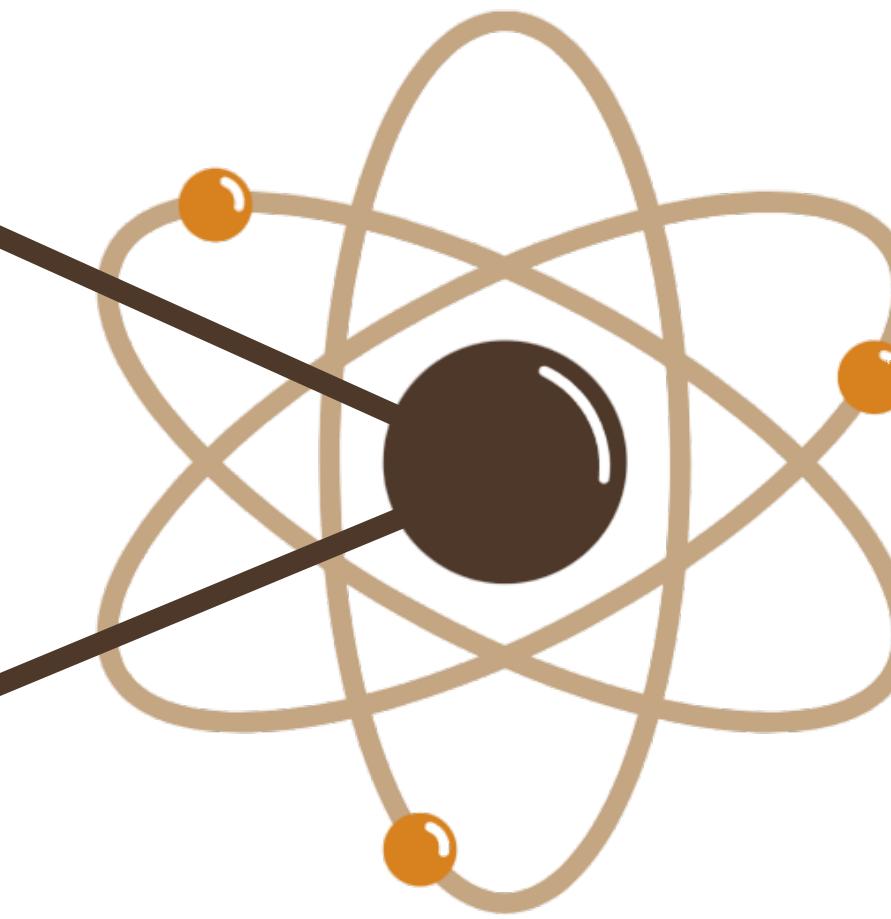
Atom
($\sim 10^{-10}$ m)

$$\begin{cases} m_p = 938 \text{ MeV} \\ c_p = +1 \text{ e} \end{cases}$$

Proton



Nucleus
 $(\sim 10^{-15} \text{ m})$



Atom
 $(\sim 10^{-10} \text{ m})$

$$\begin{cases} m_e = 0.5 \text{ MeV} \\ c_e = -1 \text{ e} \end{cases}$$

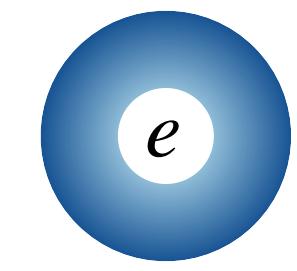
Electron
 e

Neutron

$$\begin{cases} m_n = 940 \text{ MeV} \\ c_n = 0 \end{cases}$$

$$\begin{cases} m_p = 938 \text{ MeV} \\ c_p = +1 \text{ e} \end{cases}$$

Proton

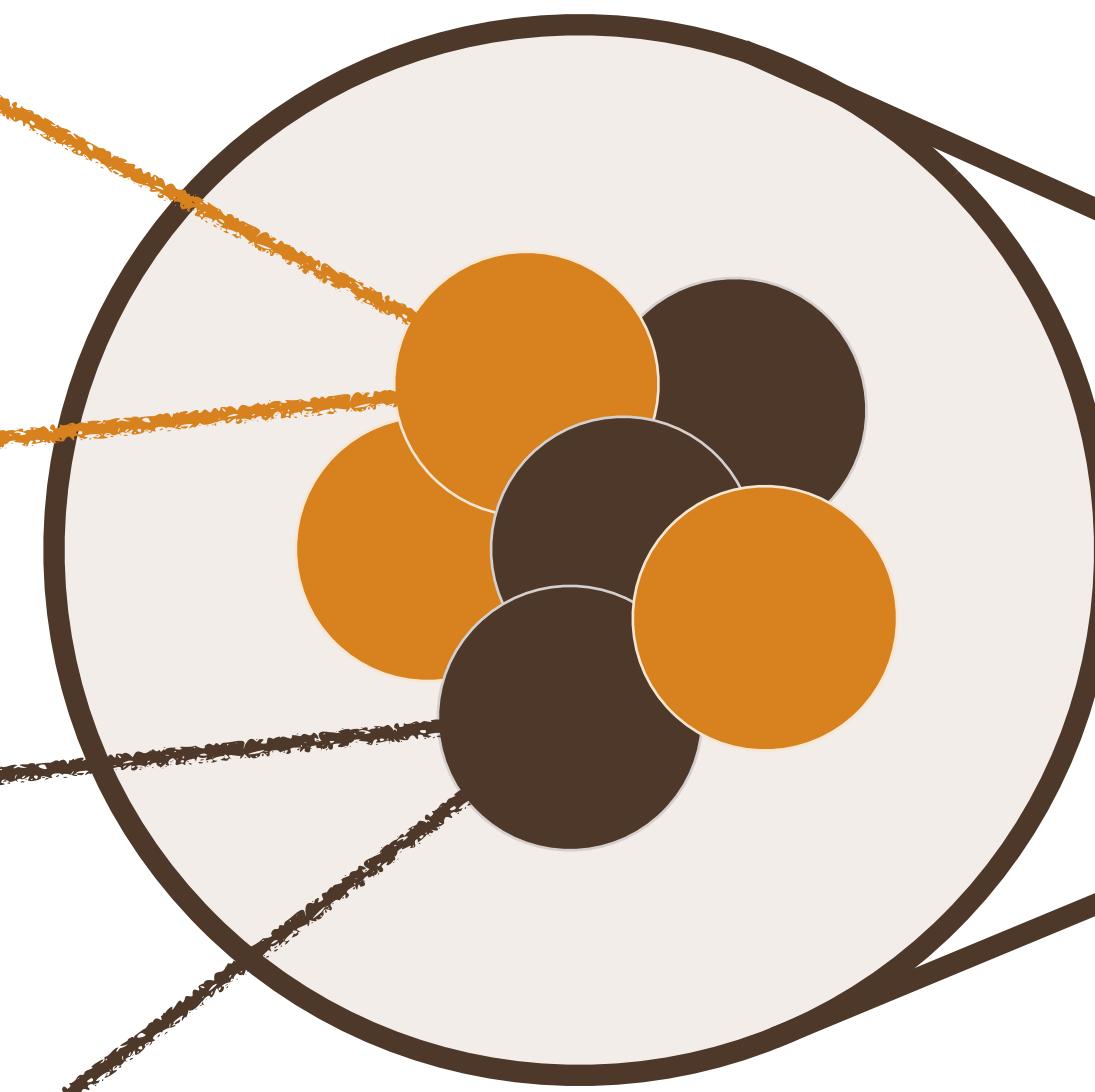
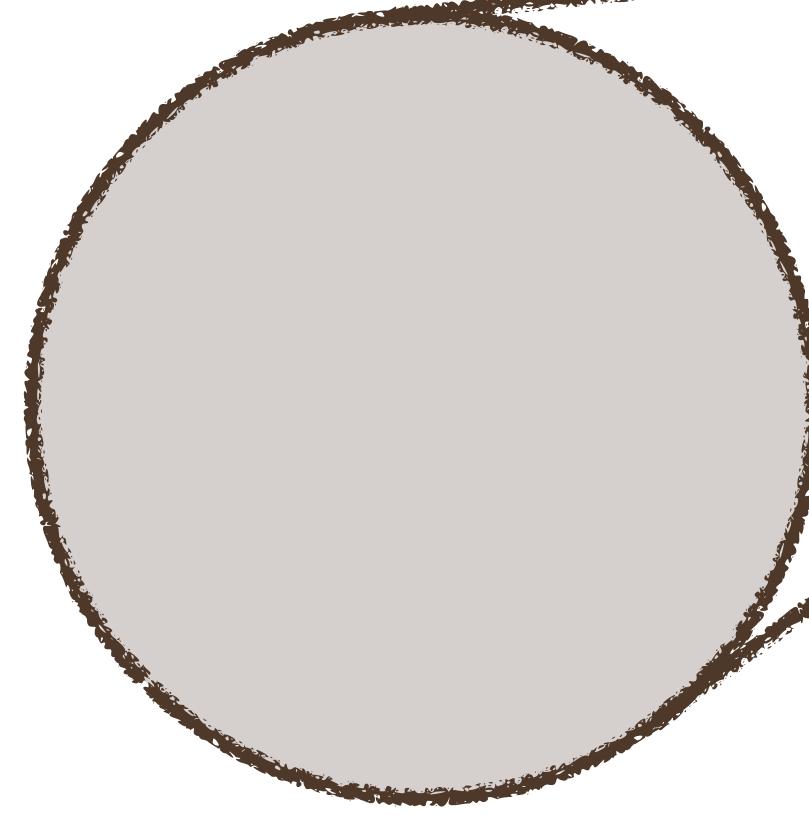
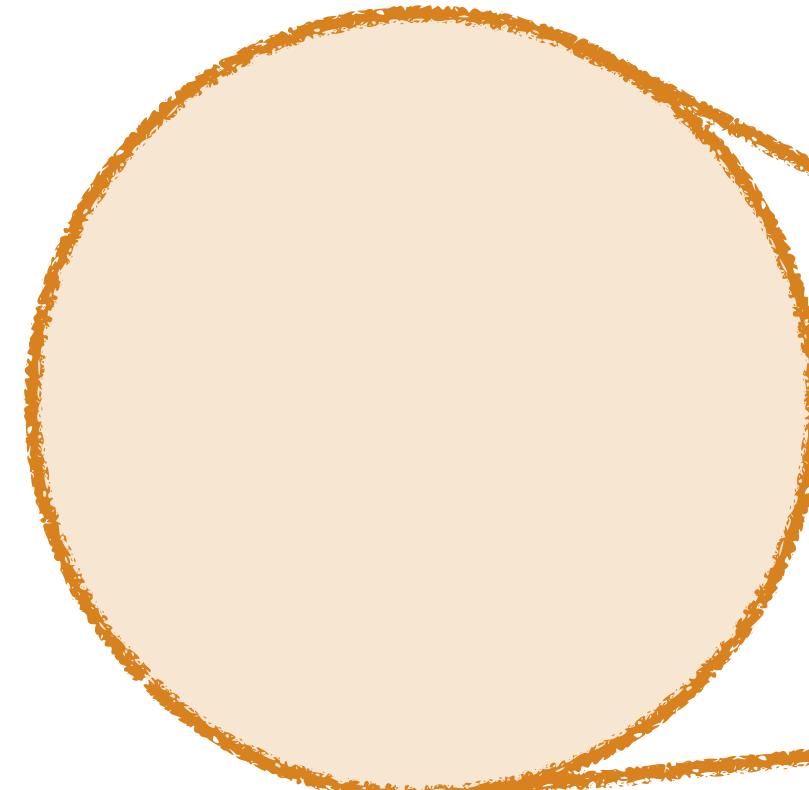


Electron

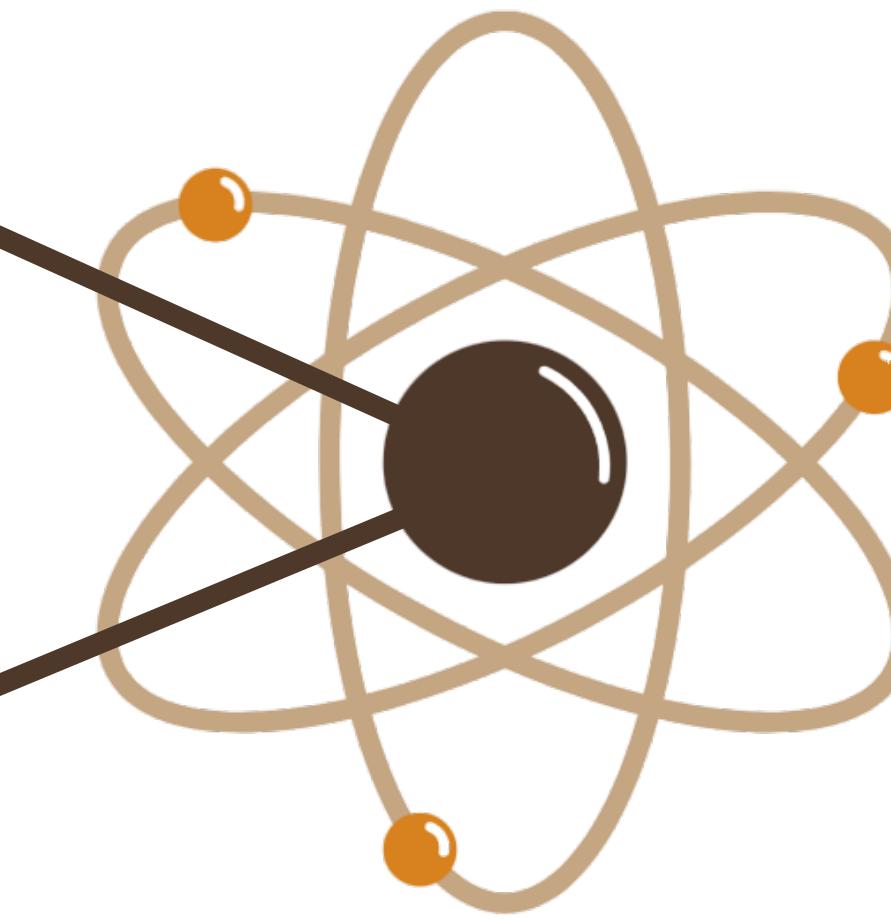
$$\begin{cases} m_e = 0.5 \text{ MeV} \\ c_e = -1 \text{ e} \end{cases}$$

$$\begin{cases} m_p = 938 \text{ MeV} \\ c_p = +1 \text{ e} \end{cases}$$

Proton



Nucleus
 $(\sim 10^{-15} \text{ m})$



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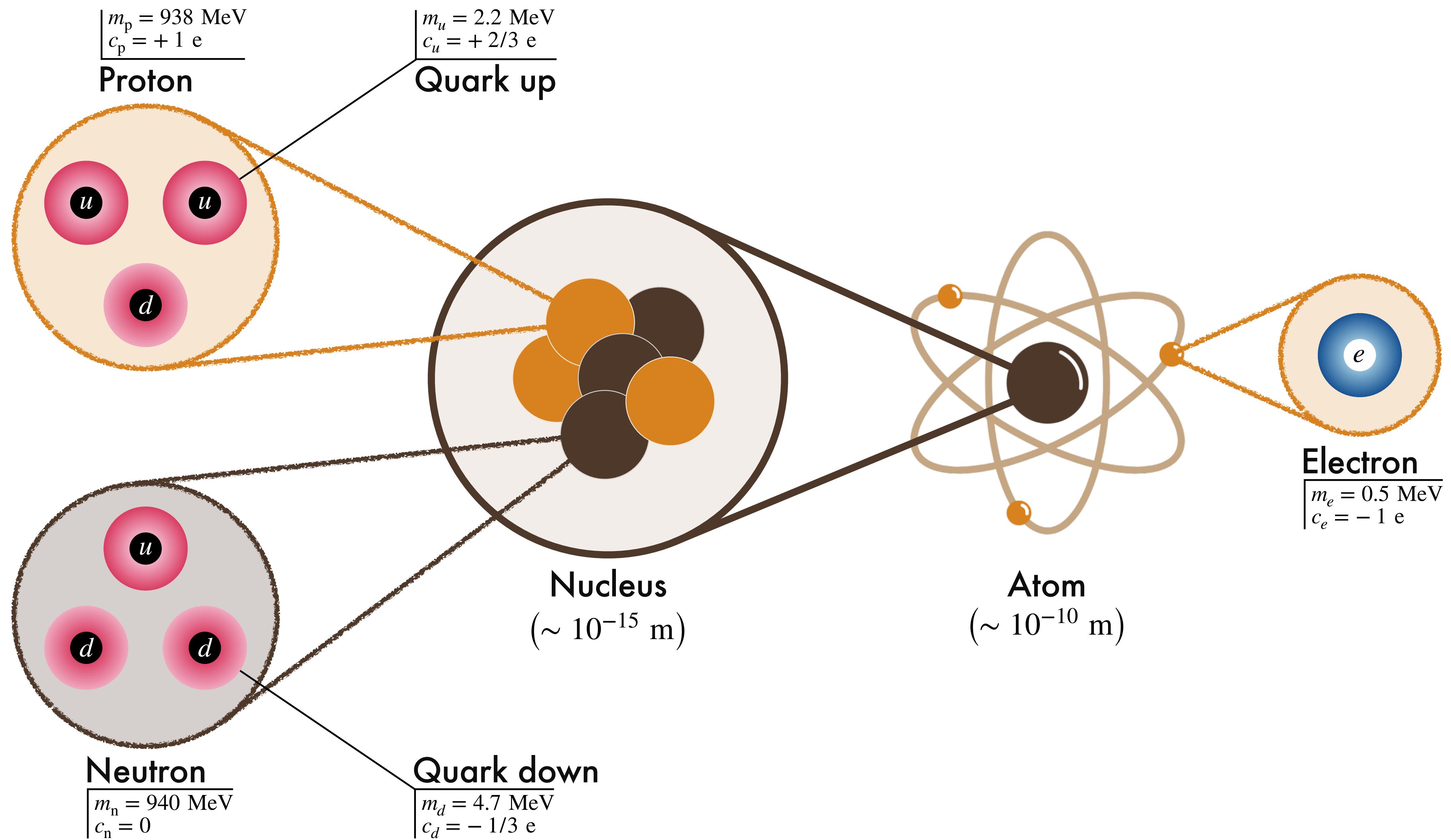
Electron

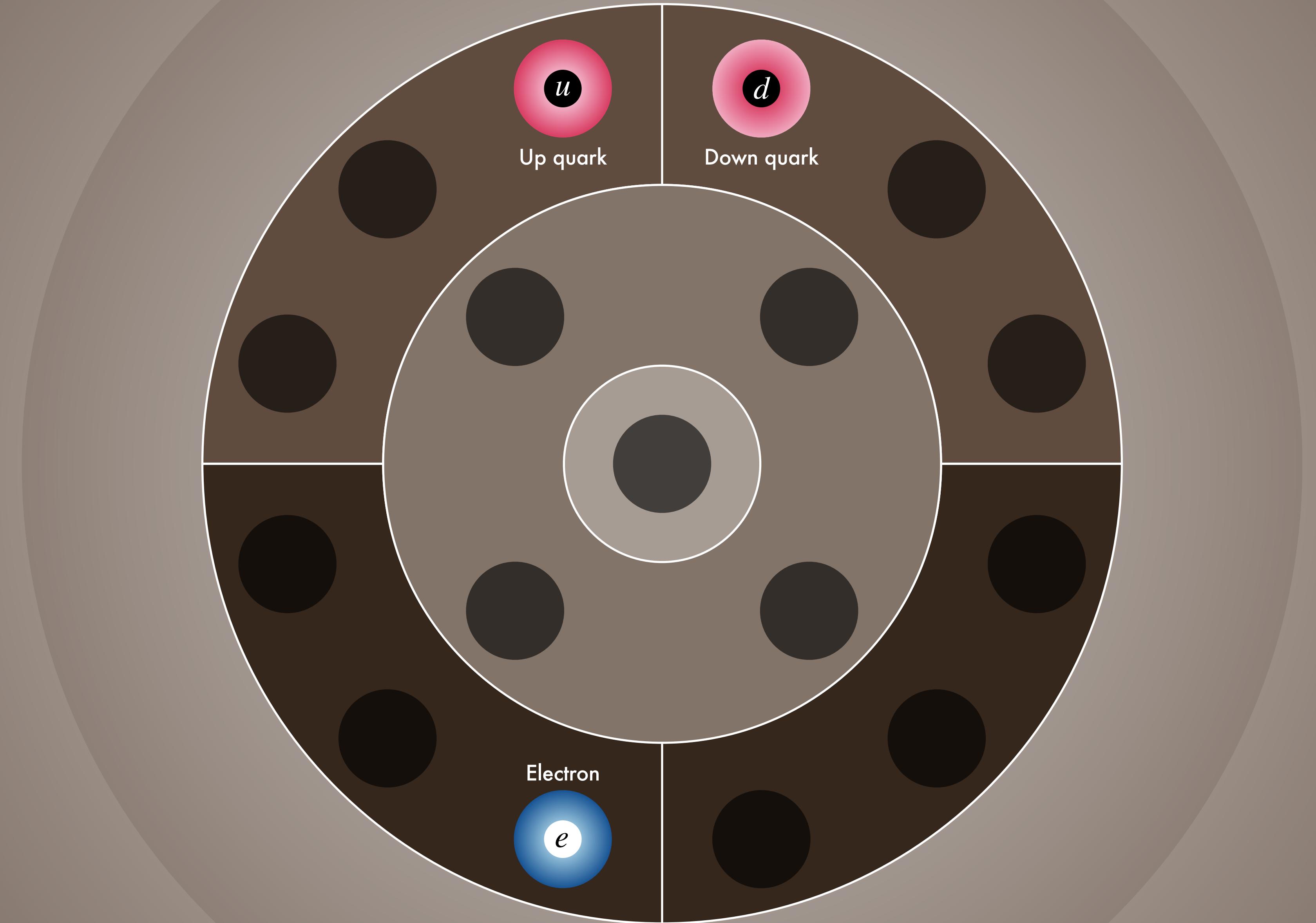
$$\begin{cases} m_e = 0.5 \text{ MeV} \\ c_e = -1 \text{ e} \end{cases}$$

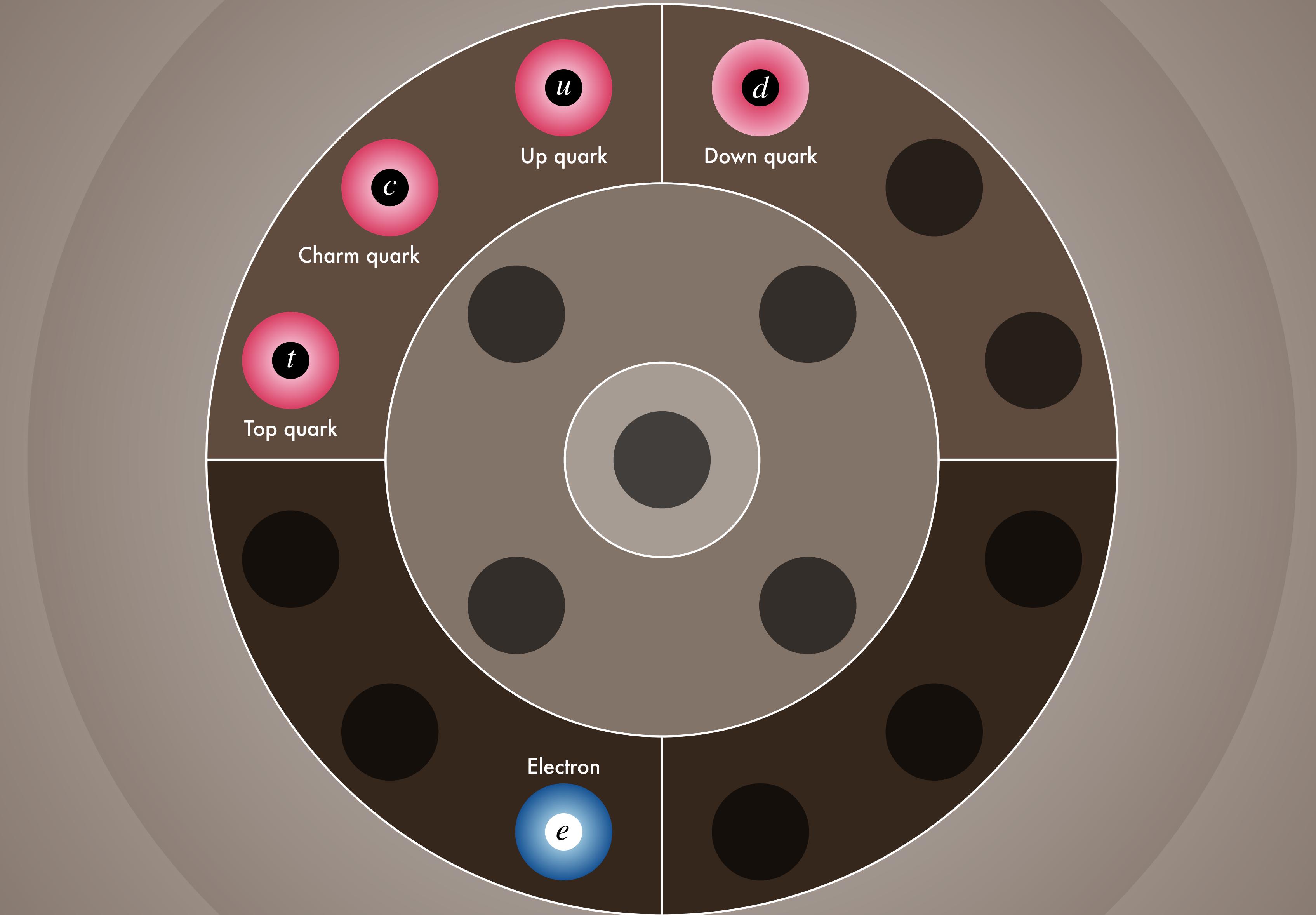
Electron

$$\begin{cases} m_n = 940 \text{ MeV} \\ c_n = 0 \end{cases}$$

Neutron





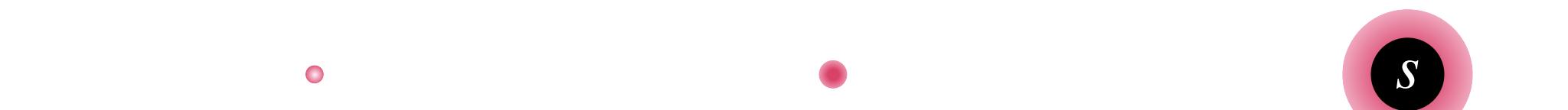




t

Quark top

$$\begin{cases} m_t = 173 \text{ GeV} \\ c_t = + 2/3 \text{ e} \end{cases}$$



.

Quark up

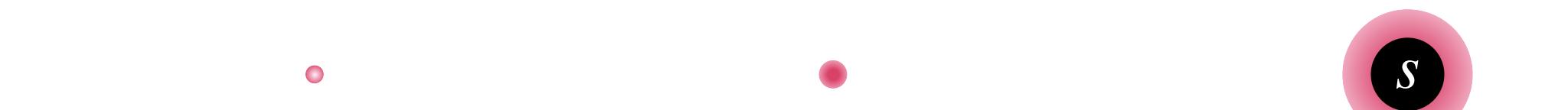
$$\begin{cases} m_u = 2.2 \text{ MeV} \\ c_u = + 2/3 \text{ e} \end{cases}$$



.

Quark down

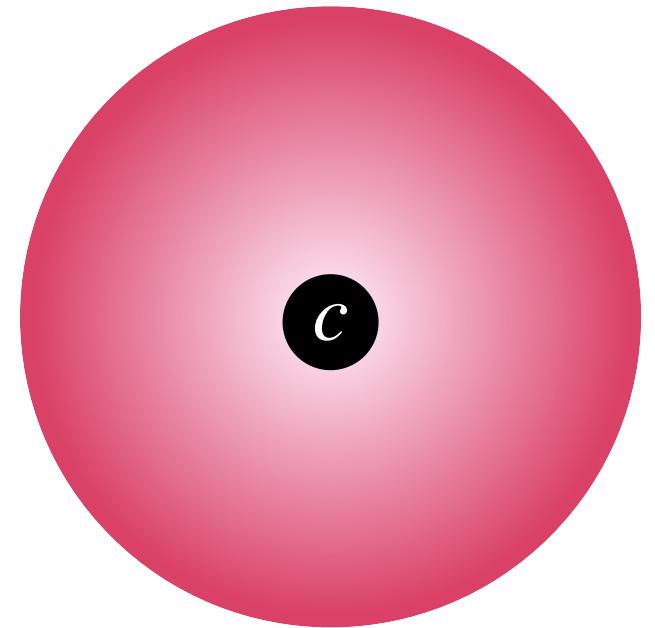
$$\begin{cases} m_d = 4.7 \text{ MeV} \\ c_d = - 1/3 \text{ e} \end{cases}$$



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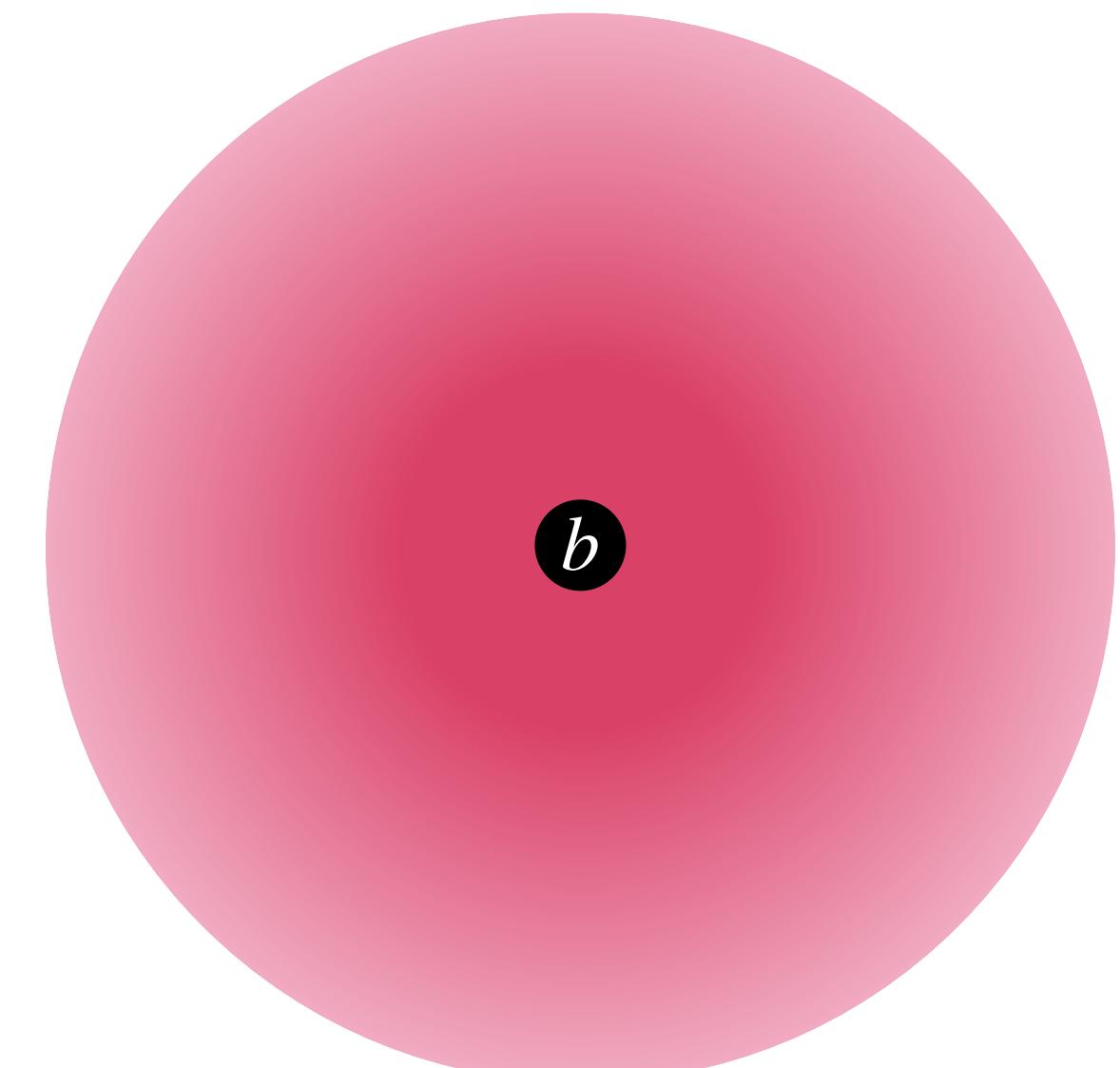
Quark strange

$$\begin{cases} m_s = 96 \text{ MeV} \\ c_s = - 1/3 \text{ e} \end{cases}$$



Quark charm

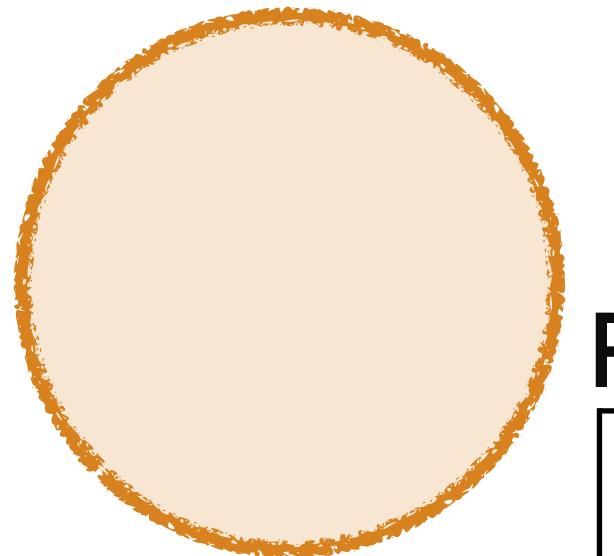
$$\begin{cases} m_c = 1.28 \text{ GeV} \\ c_c = + 2/3 \text{ e} \end{cases}$$



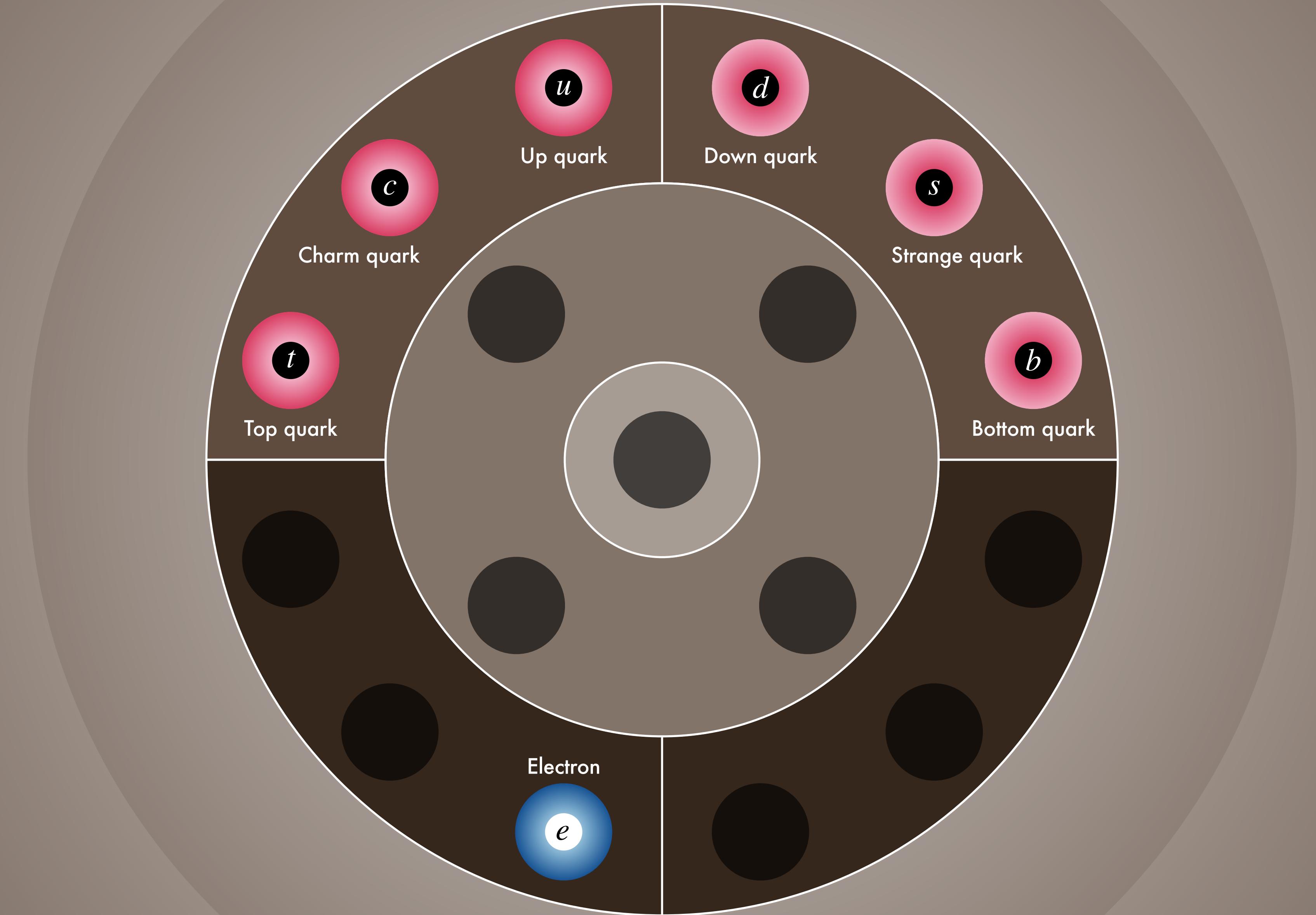
b

Quark bottom

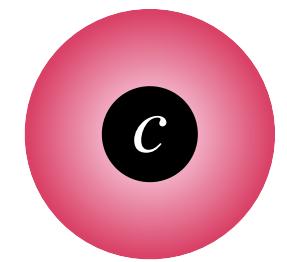
$$\begin{cases} m_b = 4.18 \text{ GeV} \\ c_b = - 1/3 \text{ e} \end{cases}$$



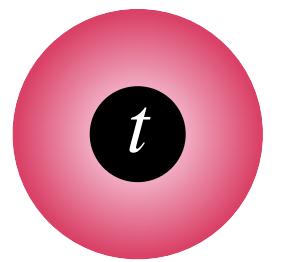
$$\begin{cases} m_p = 938 \text{ MeV} \\ c_p = + 1 \text{ e} \end{cases}$$



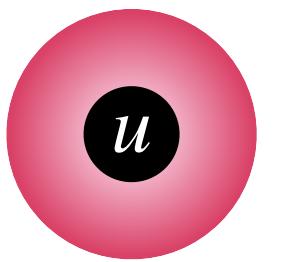
THE MATTER



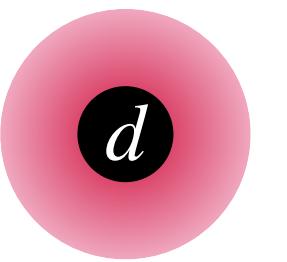
Quark
charm



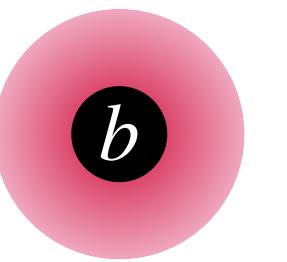
Quark
top



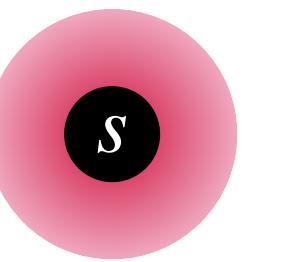
Quark
up



Quark
down

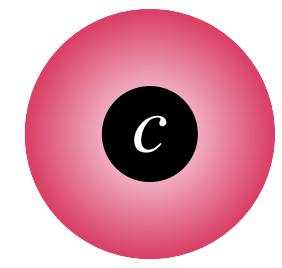


Quark
bottom

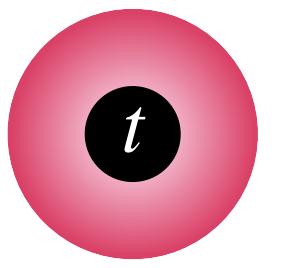


Quark
strange

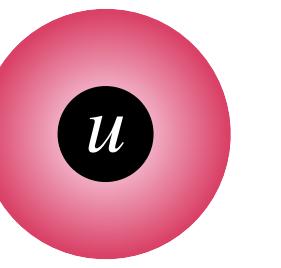
THE MATTER



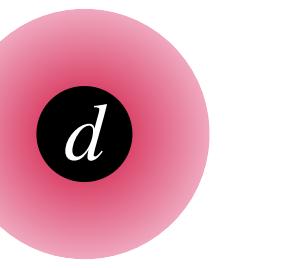
Quark
charm
 $+2/3$ e



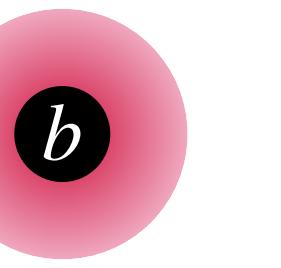
Quark
top
 $+2/3$ e



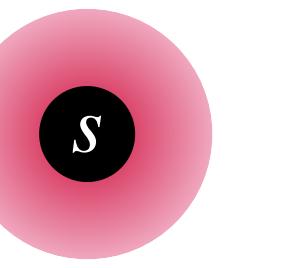
Quark
up
 $+2/3$ e



Quark
down
 $-1/3$ e

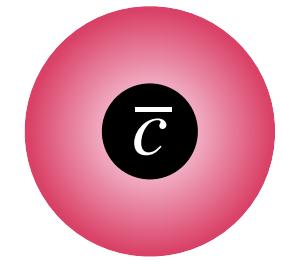


Quark
bottom
 $-1/3$ e

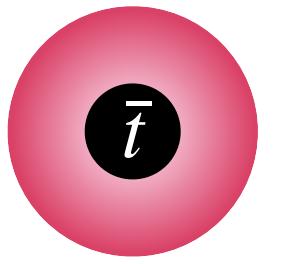


Quark
strange
 $-1/3$ e

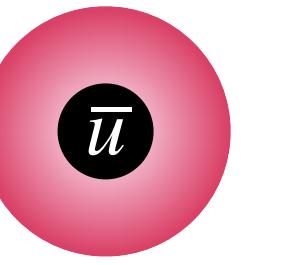
THE ANTIMATTER



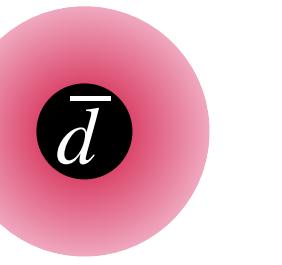
Antiquark
charm
 $-2/3$ e



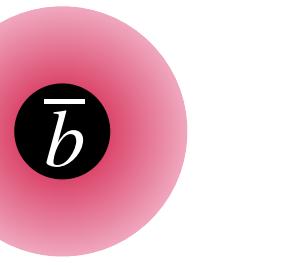
Antiquark
top
 $-2/3$ e



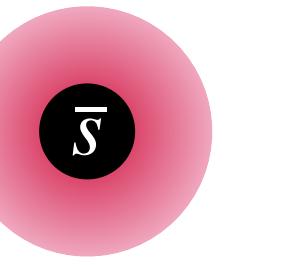
Antiquark
up
 $-2/3$ e



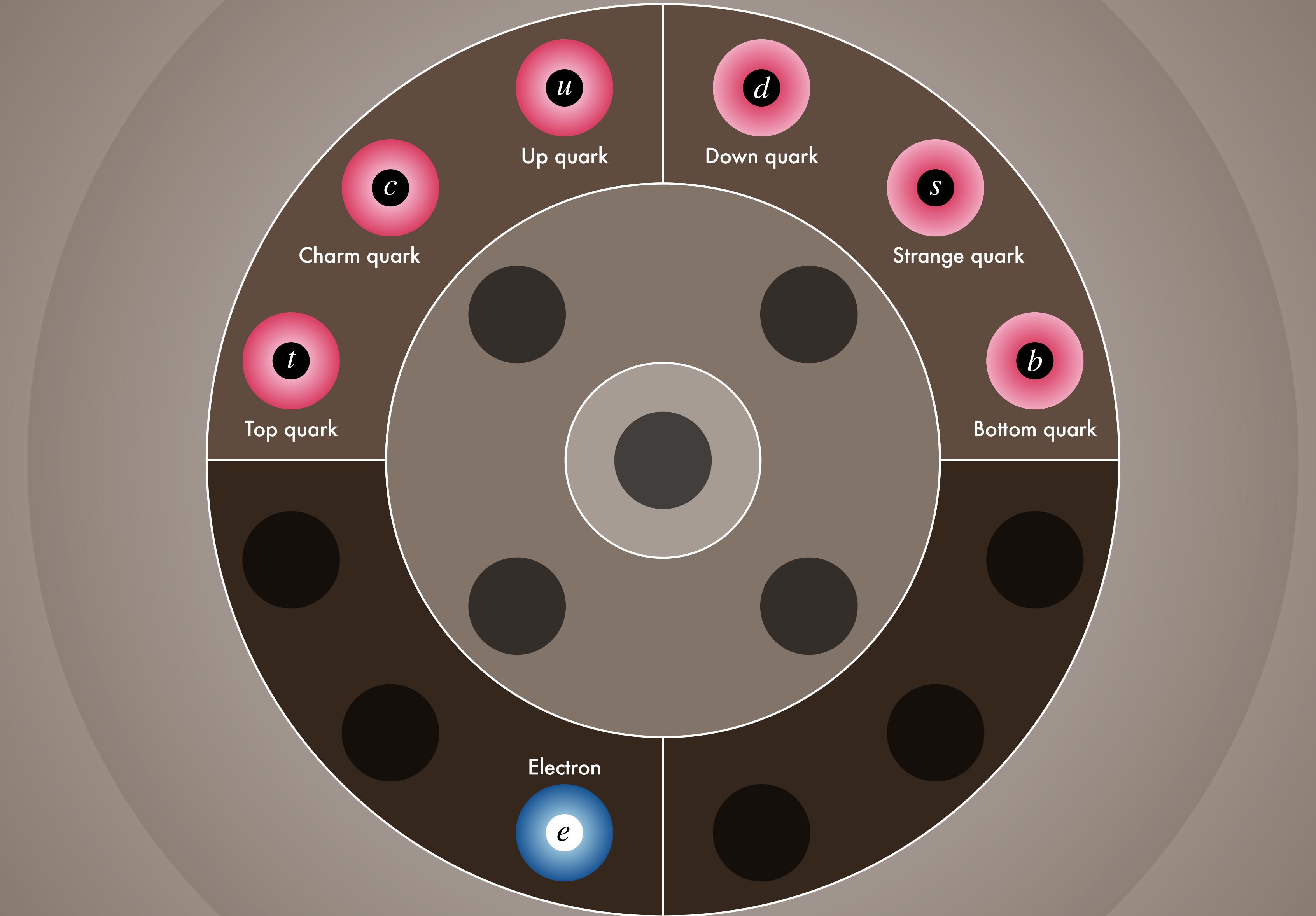
Antiquark
down
 $+1/3$ e

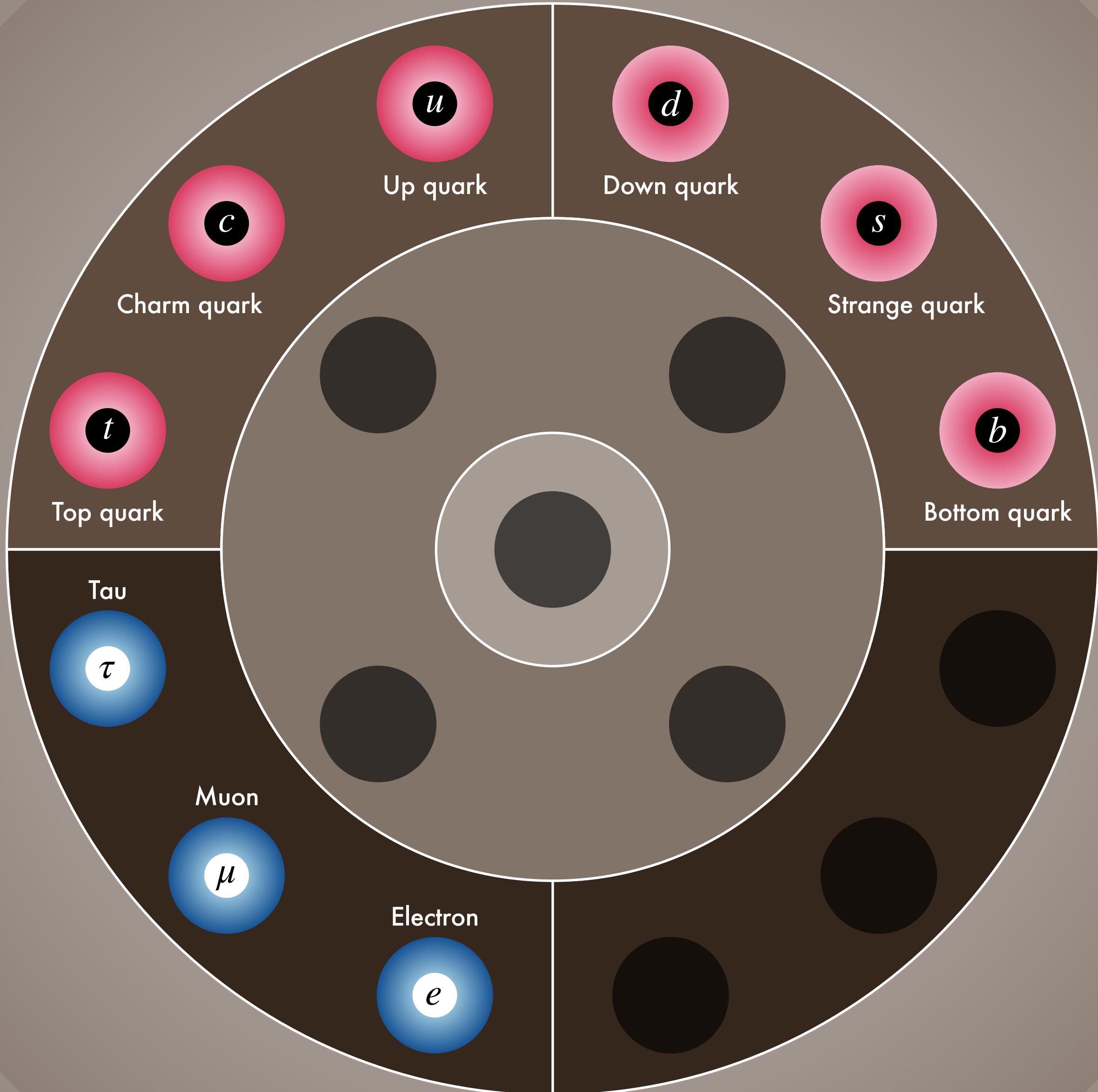


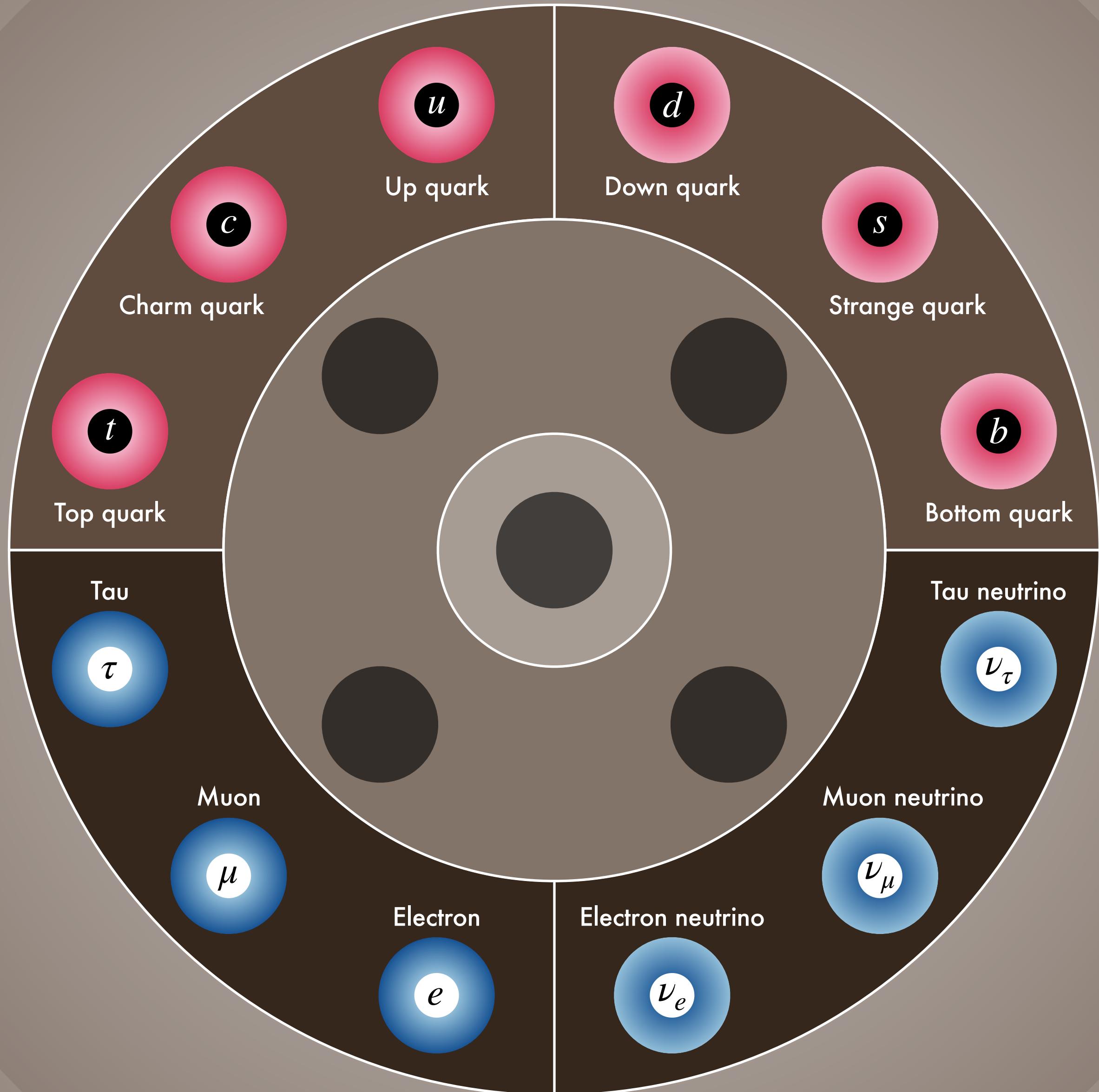
Antiquark
bottom
 $+1/3$ e



Antiquark
strange
 $+1/3$ e

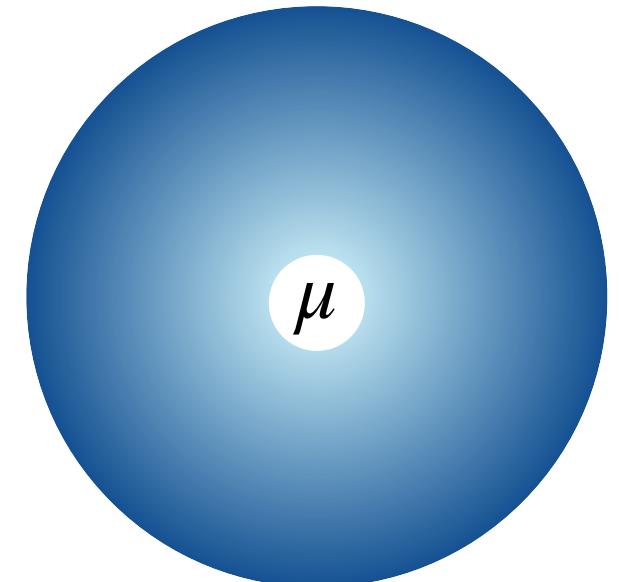






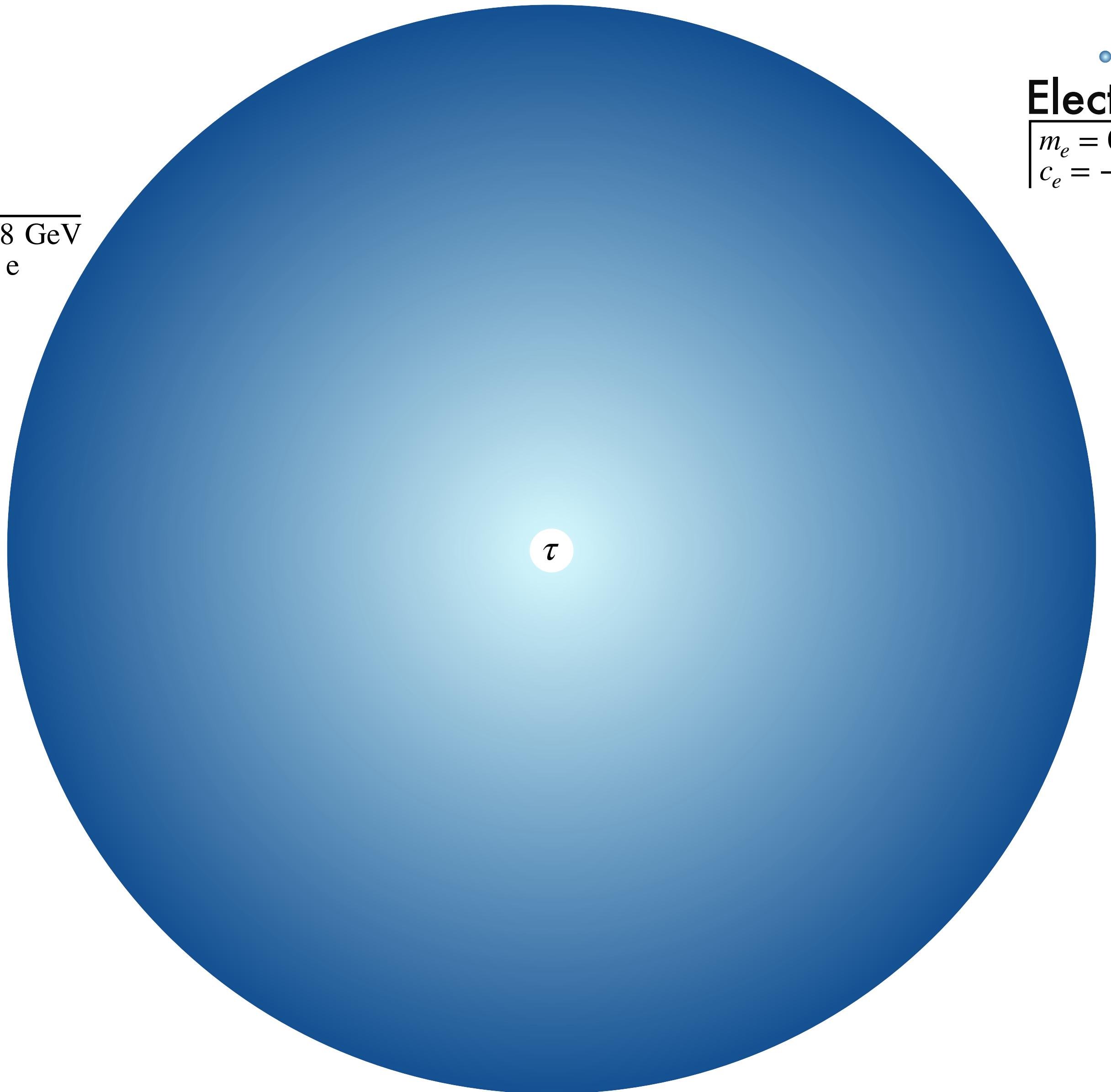
$$\begin{array}{l} m_\mu = 107 \text{ MeV} \\ c_\mu = -1 \text{ e} \end{array}$$

Muon



Tau

$$\begin{array}{l} m_\tau = 1.78 \text{ GeV} \\ c_\tau = -1 \text{ e} \end{array}$$

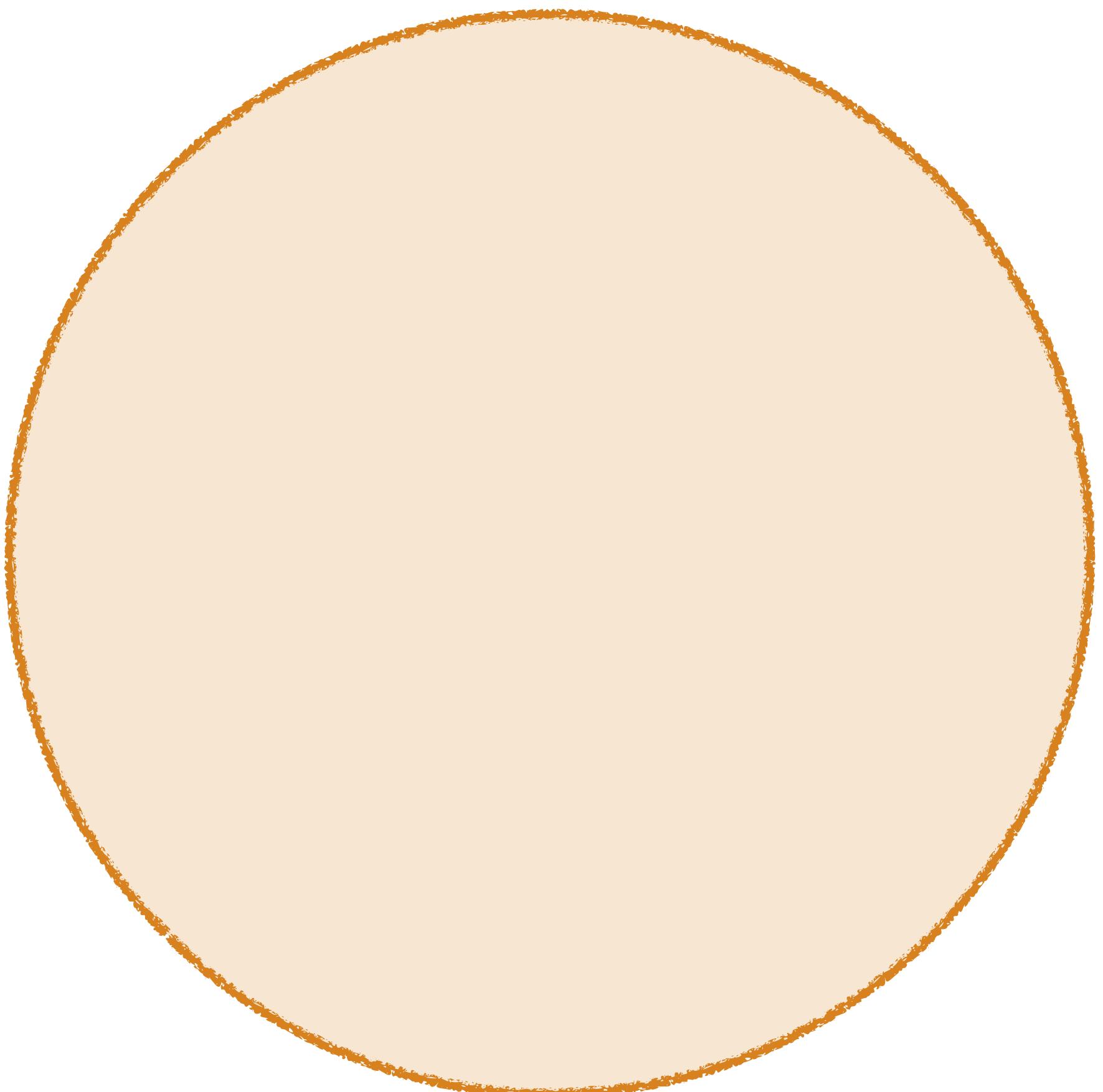


Electron

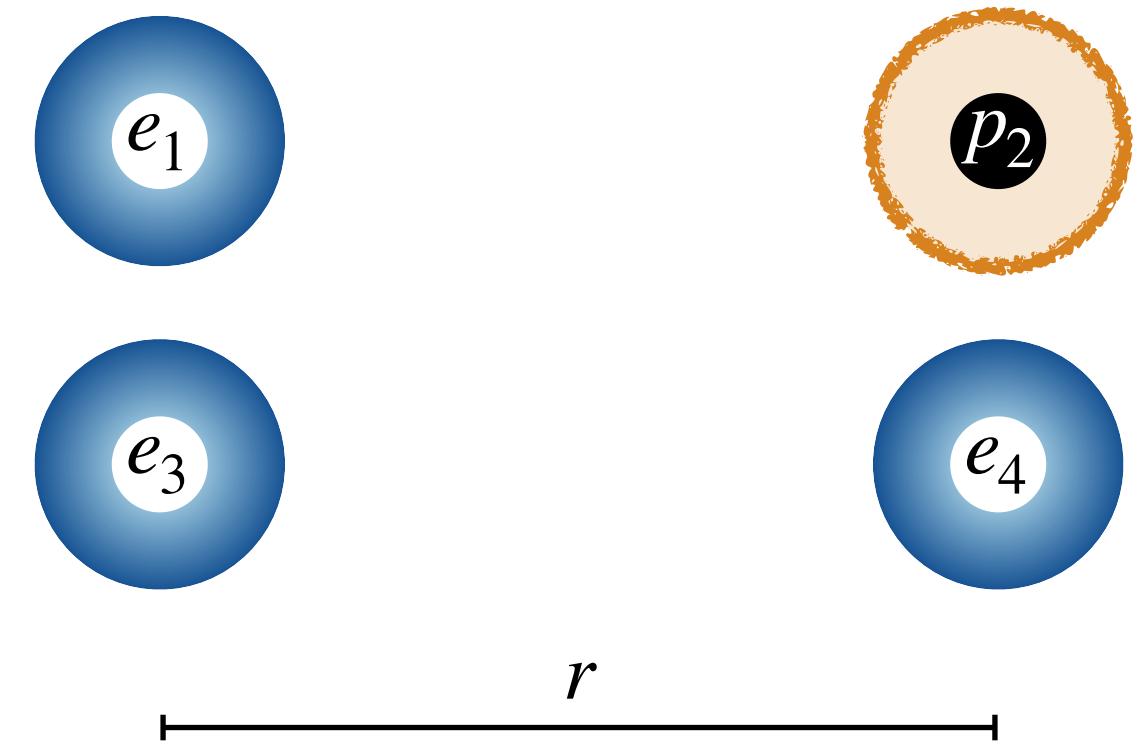
$$\begin{array}{l} m_e = 0.5 \text{ MeV} \\ c_e = -1 \text{ e} \end{array}$$

$$\begin{array}{l} m_p = 938 \text{ MeV} \\ c_p = +1 \text{ e} \end{array}$$

Proton

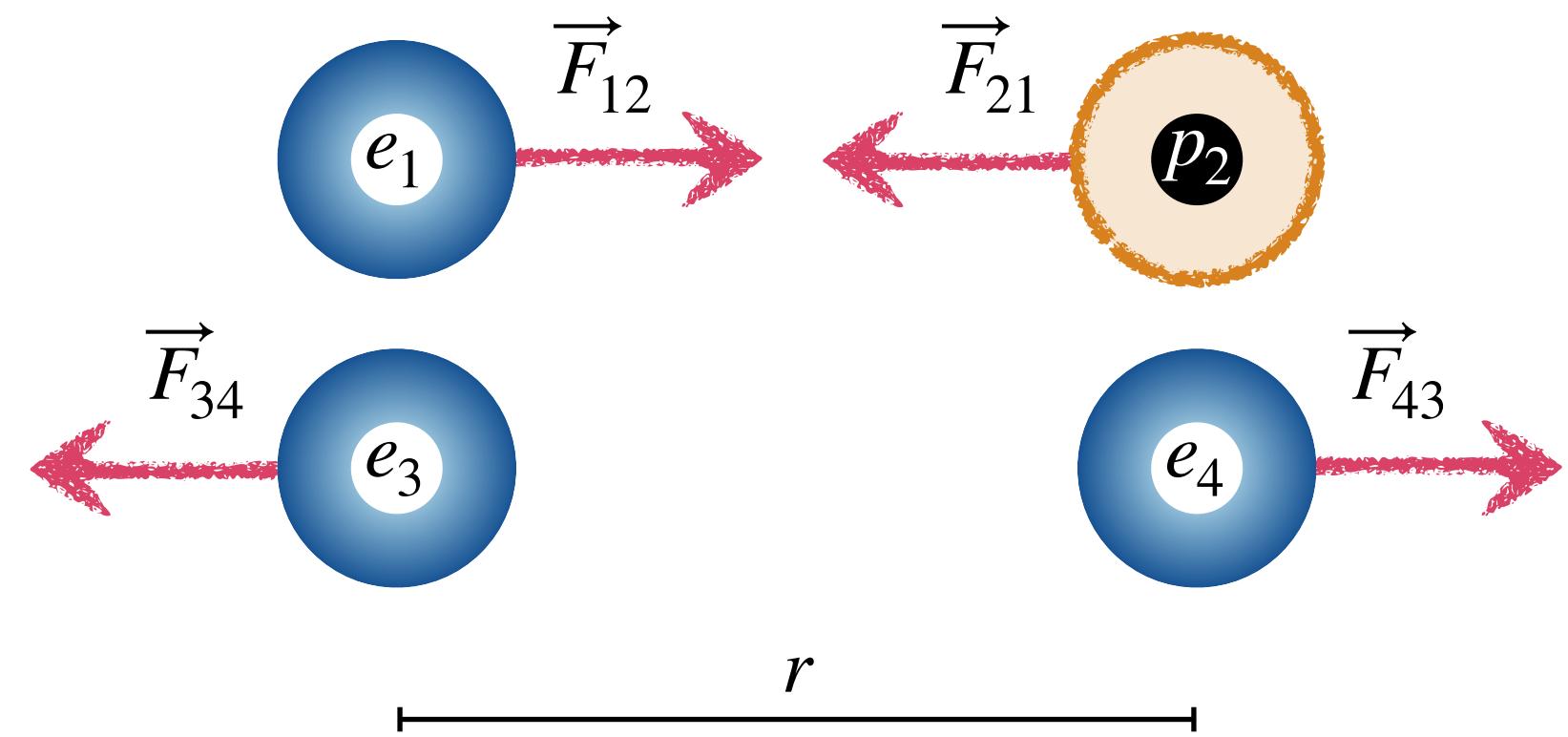


THE FORCES



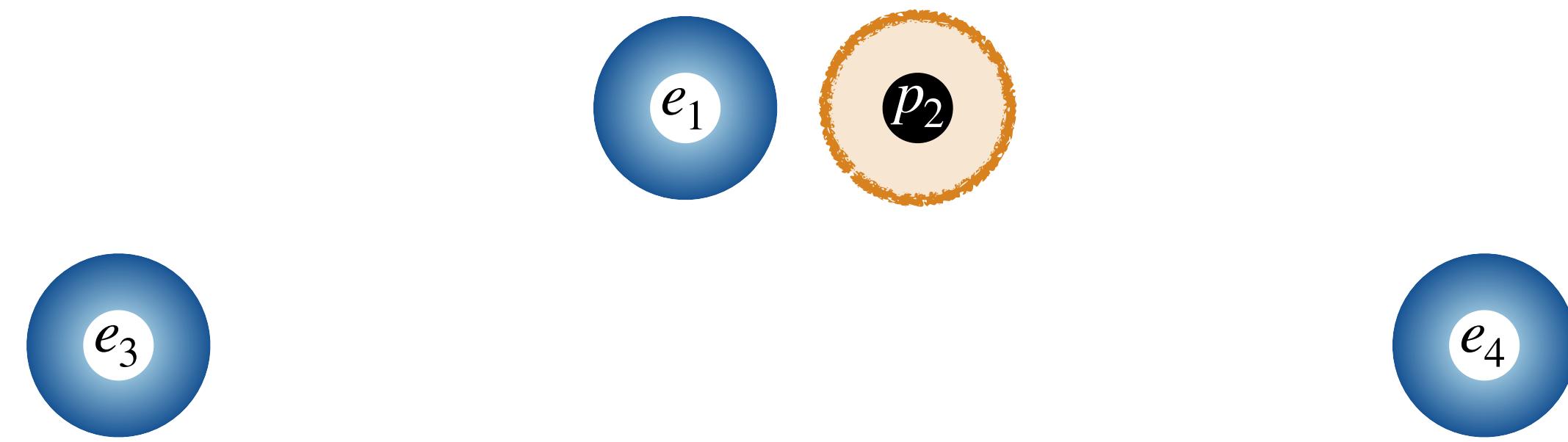
COULOMB FORCE

$$\vec{F}_{ij} = k_e \frac{q_i q_j}{r^2} \hat{r}$$

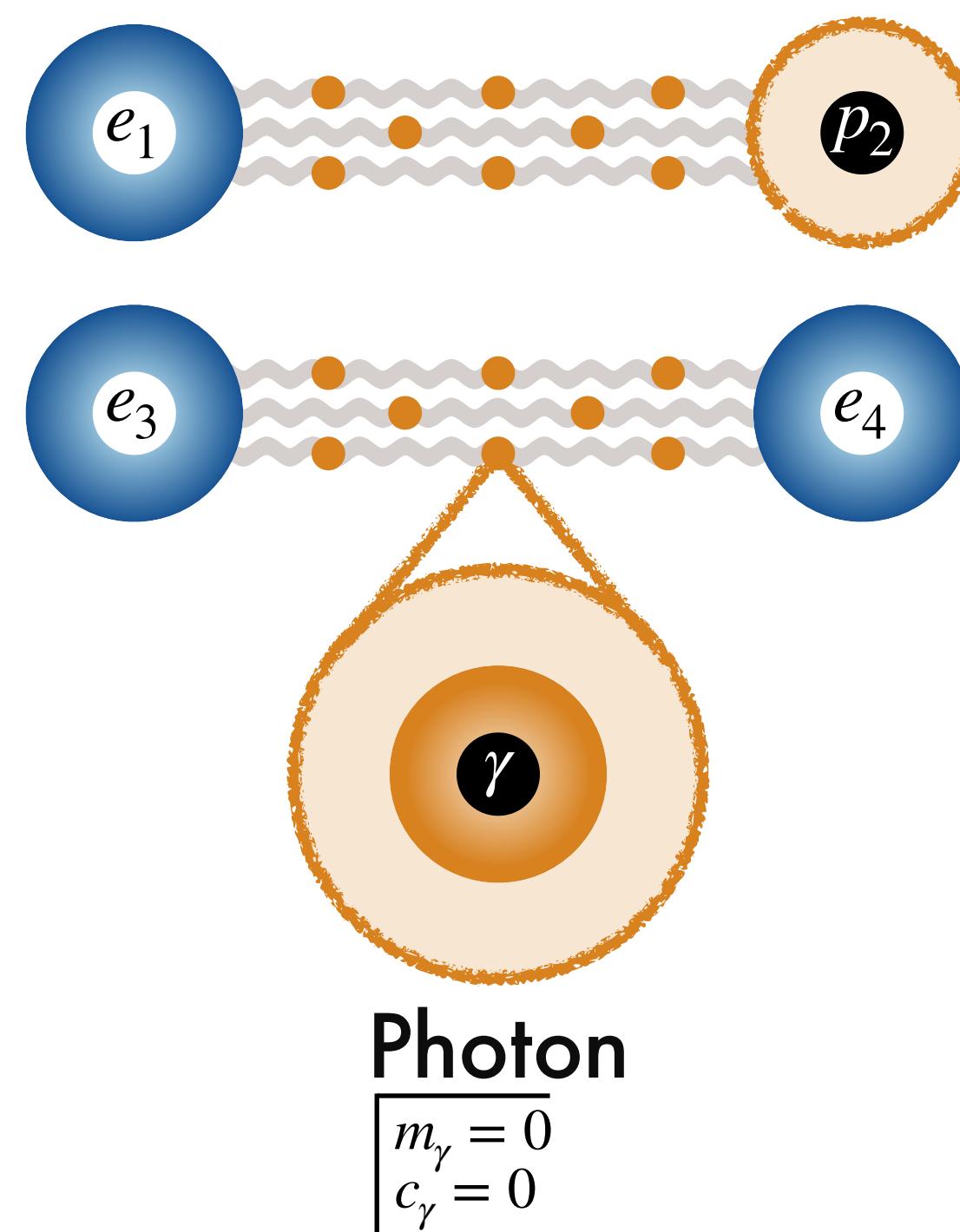


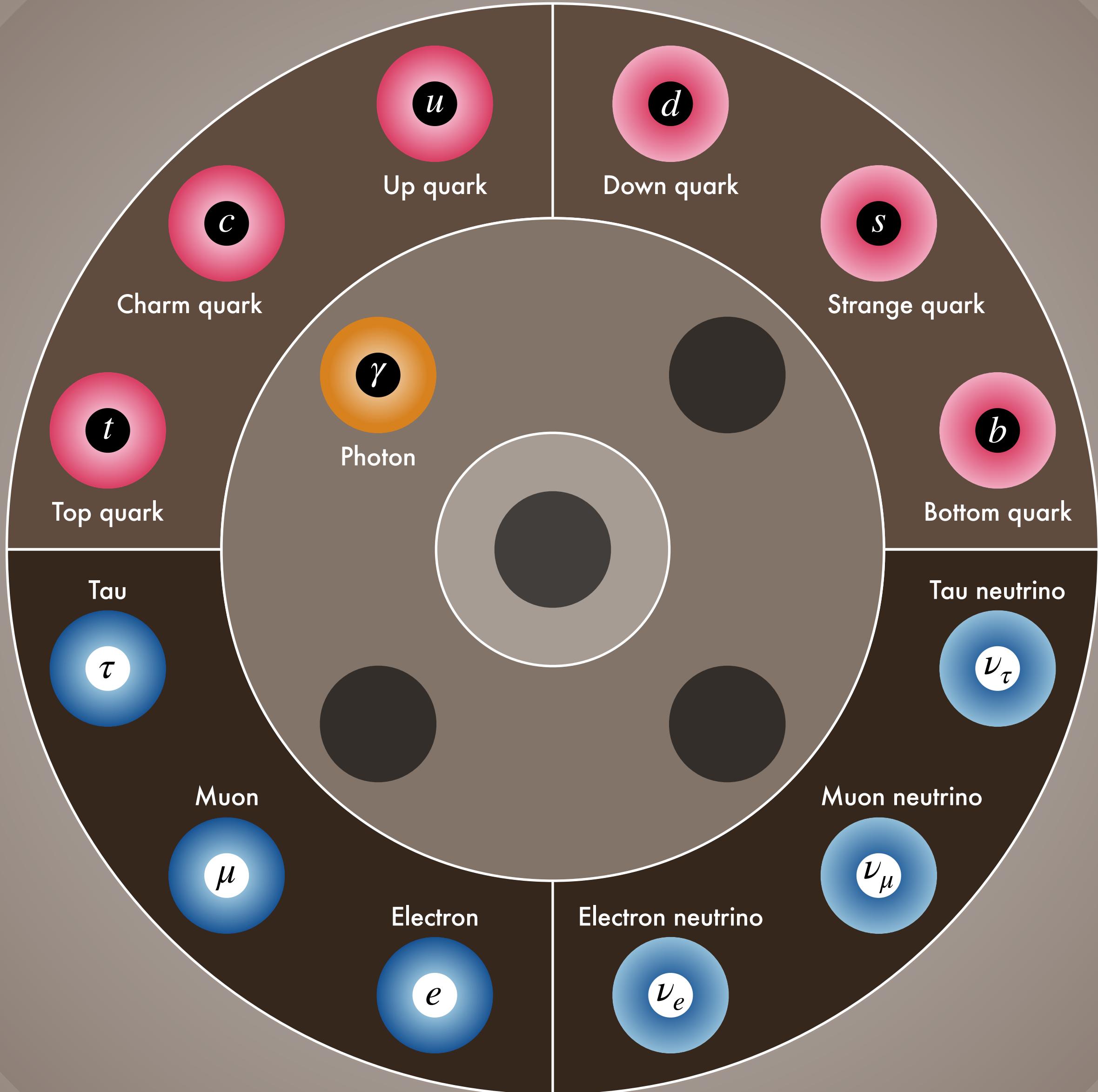
COULOMB FORCE

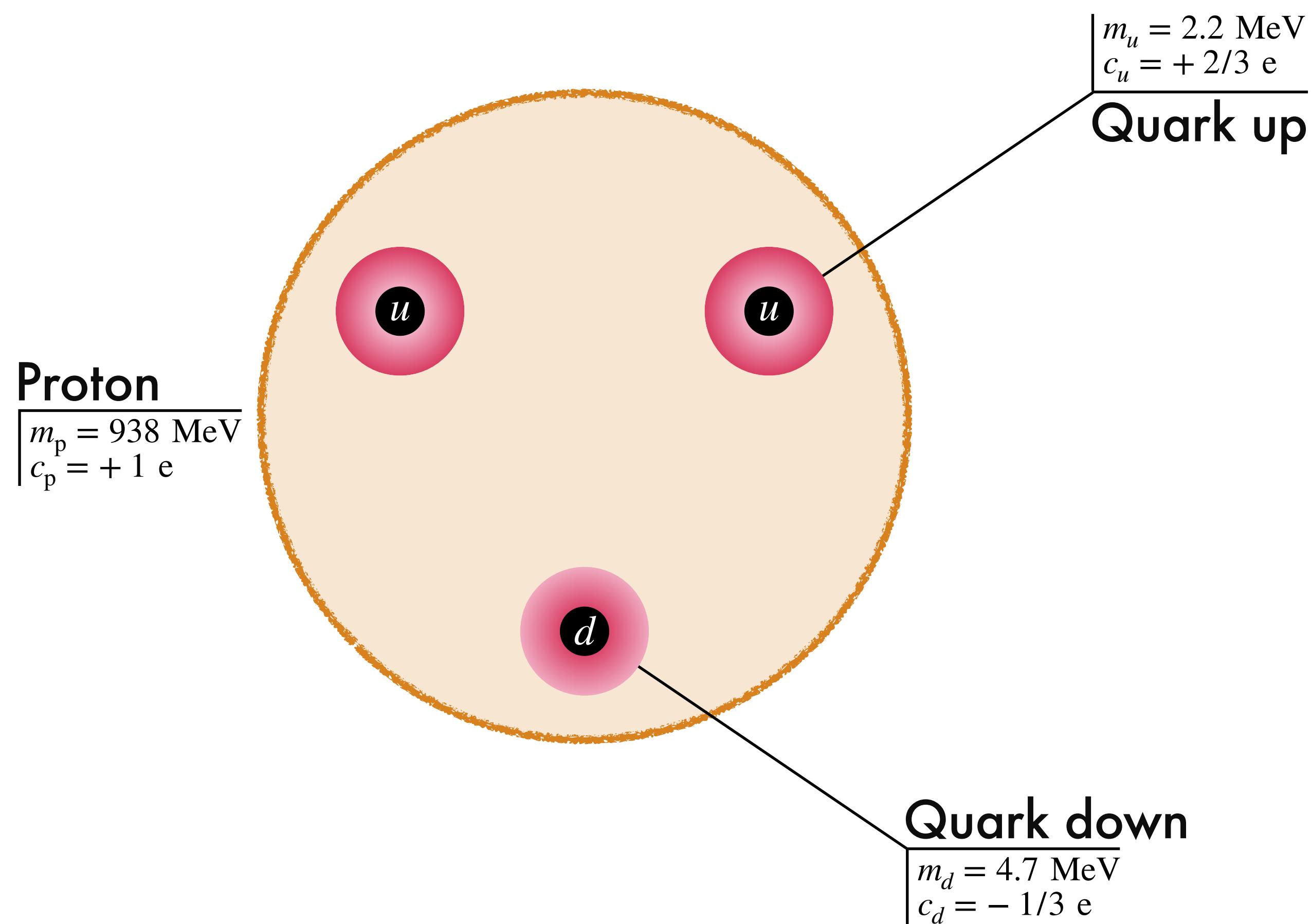
$$\vec{F}_{ij} = k_e \frac{q_i q_j}{r^2} \hat{r}$$

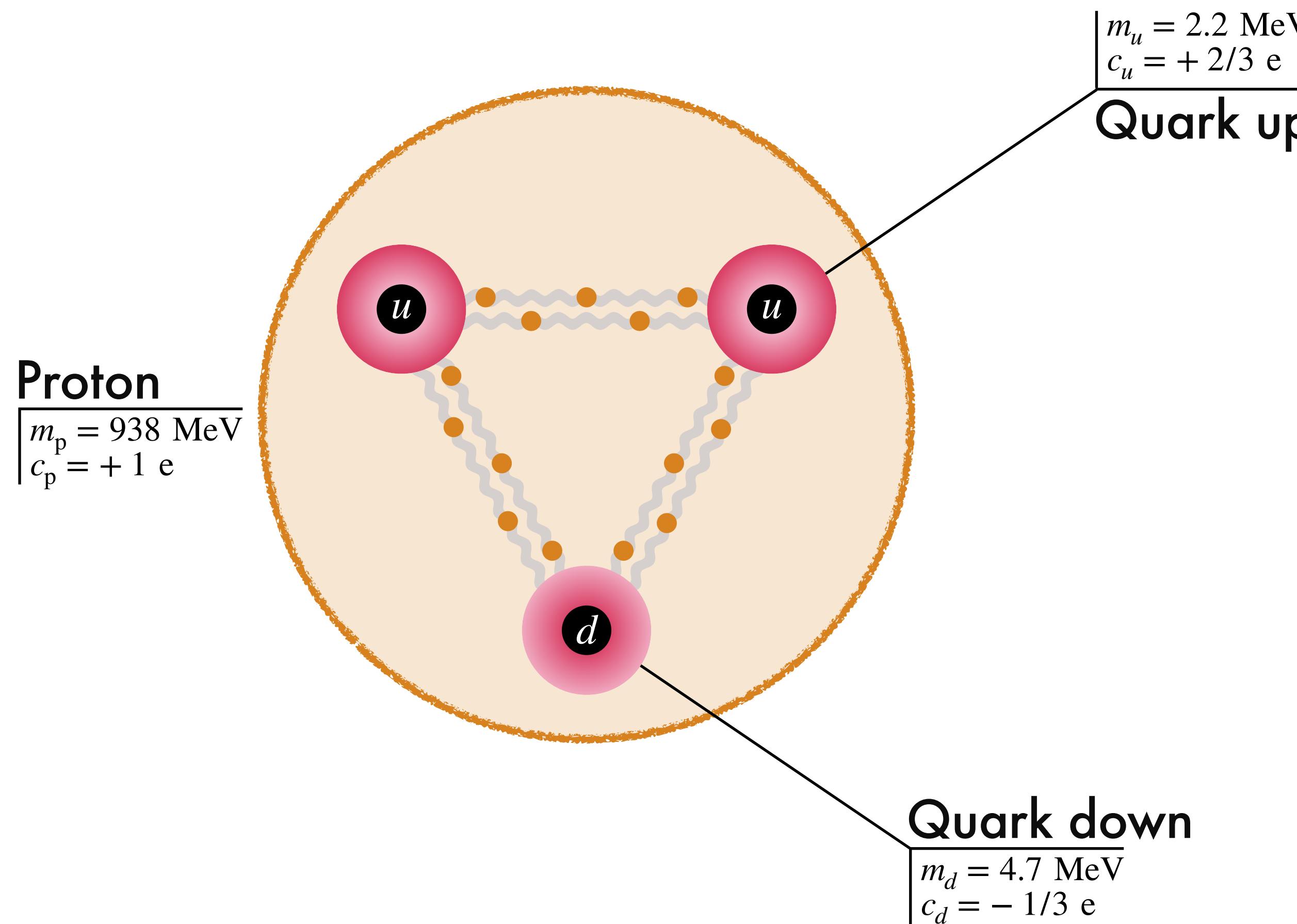


ELECTROMAGNETIC FORCE

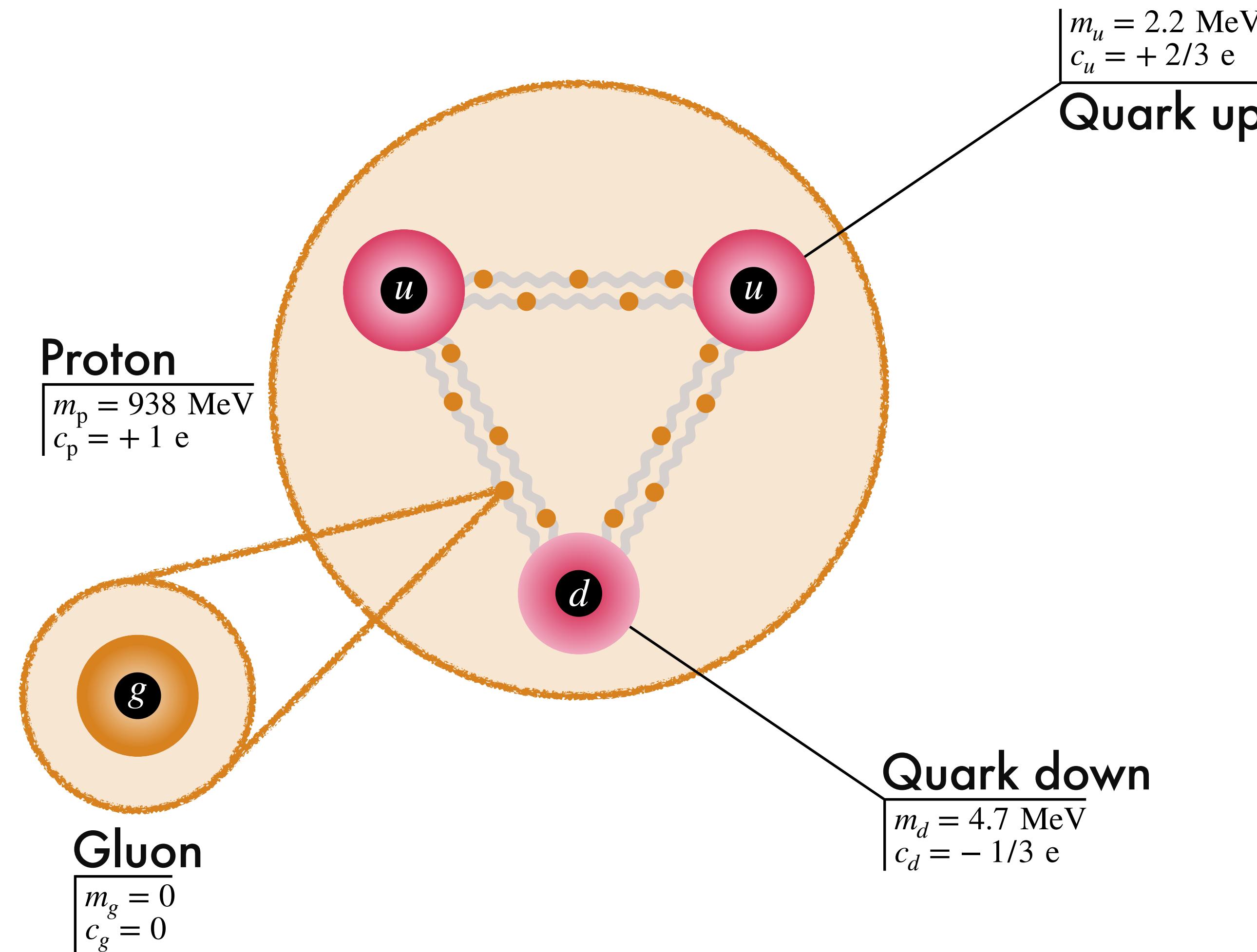


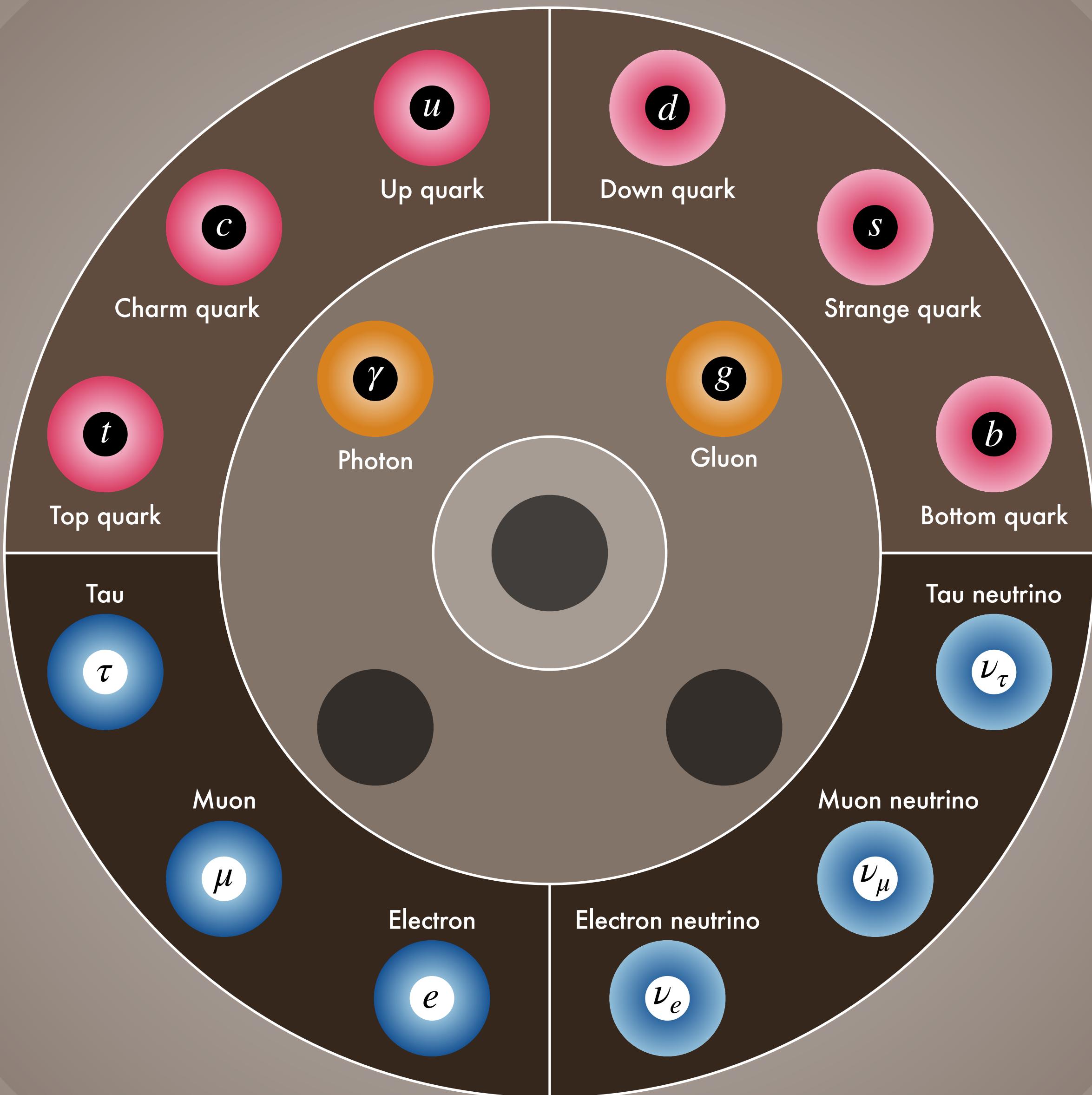


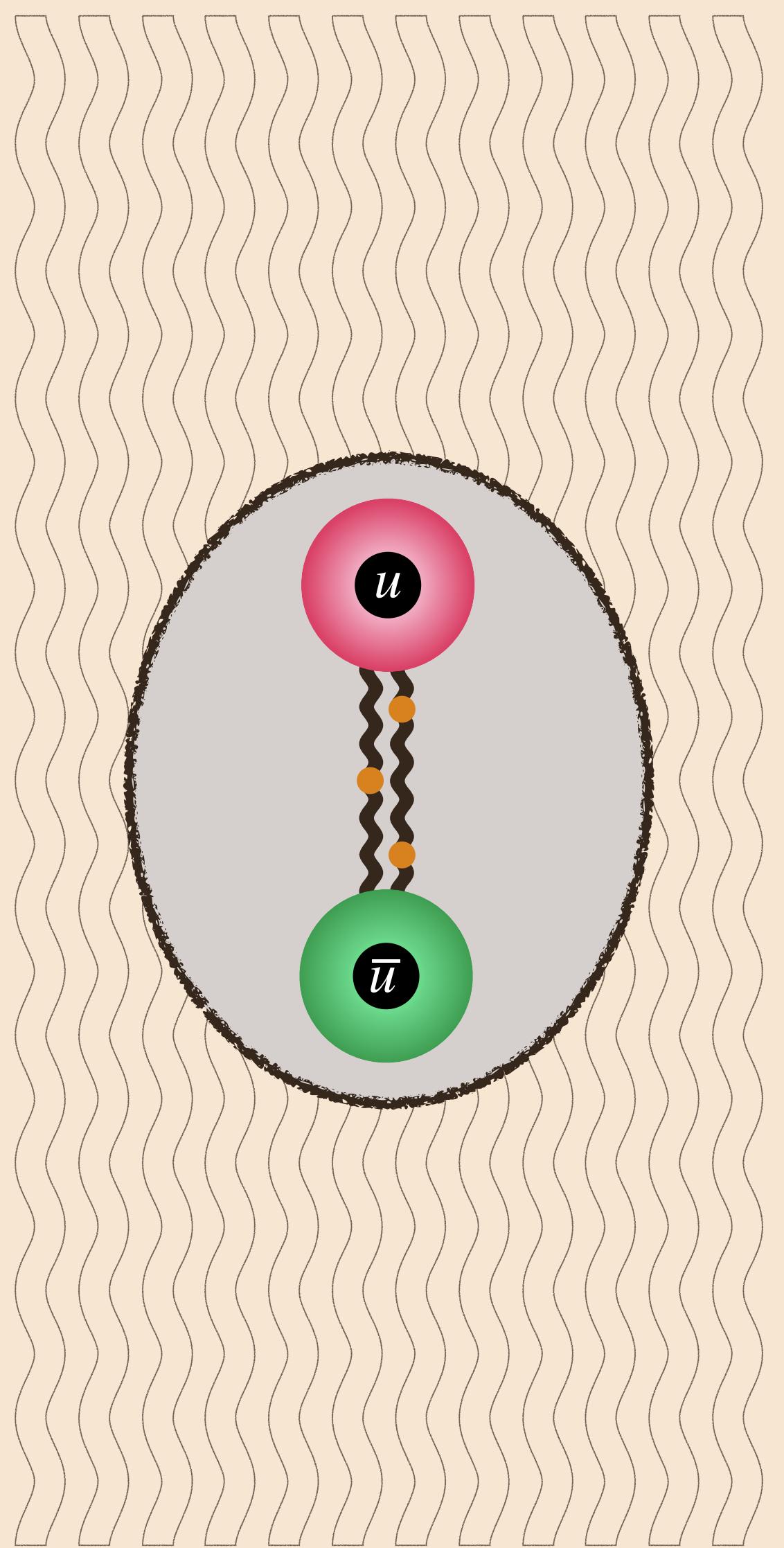


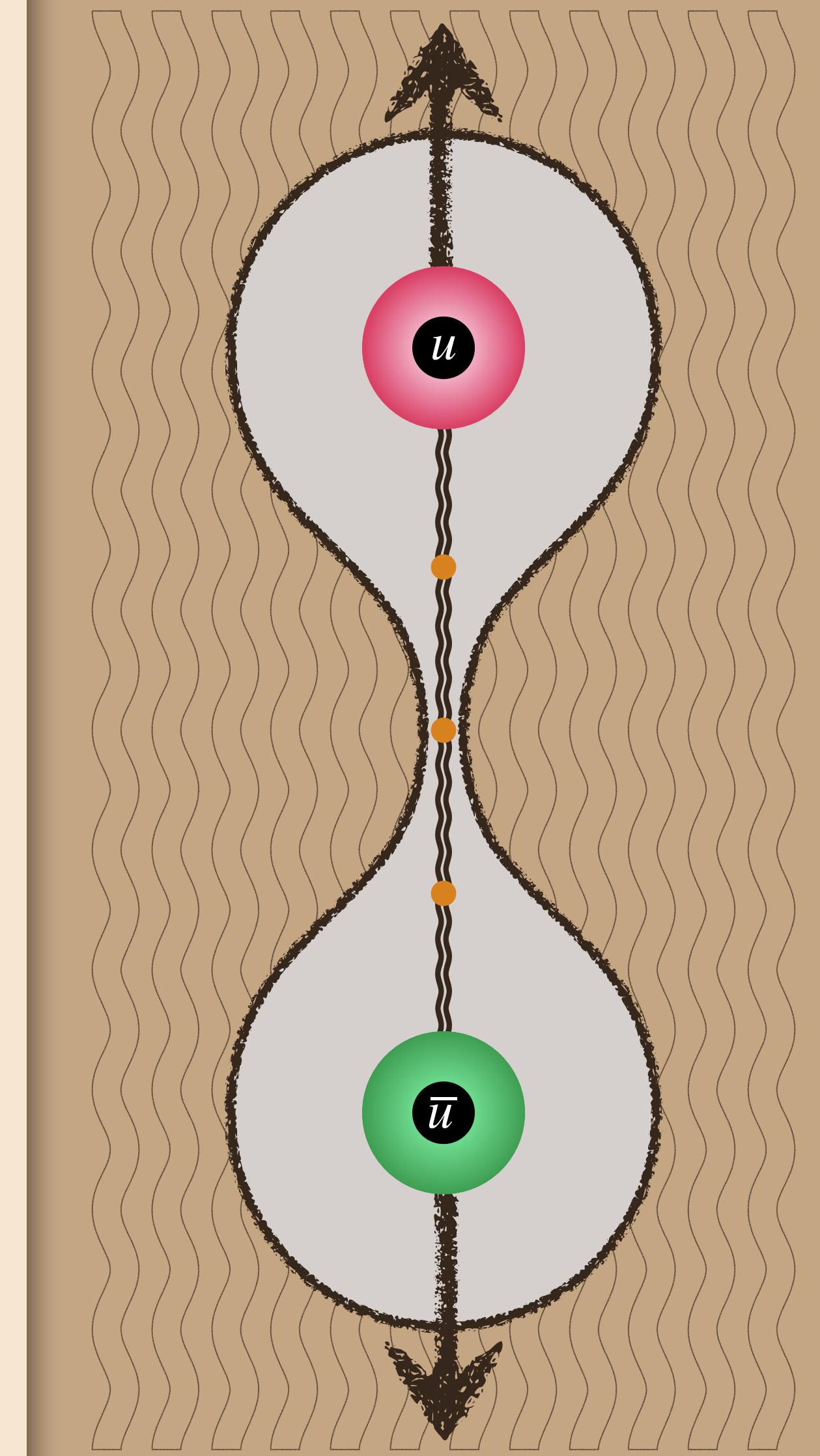
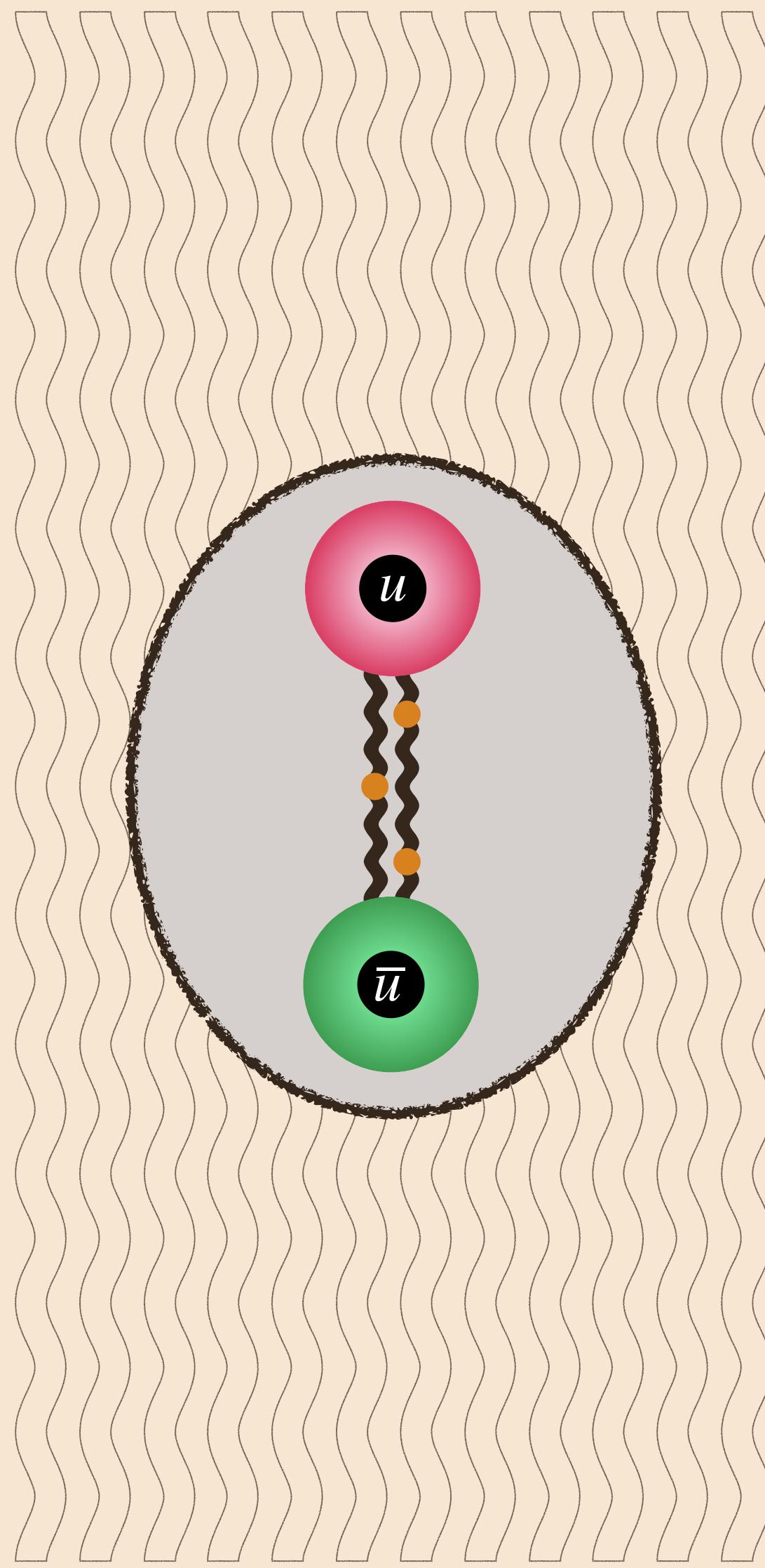


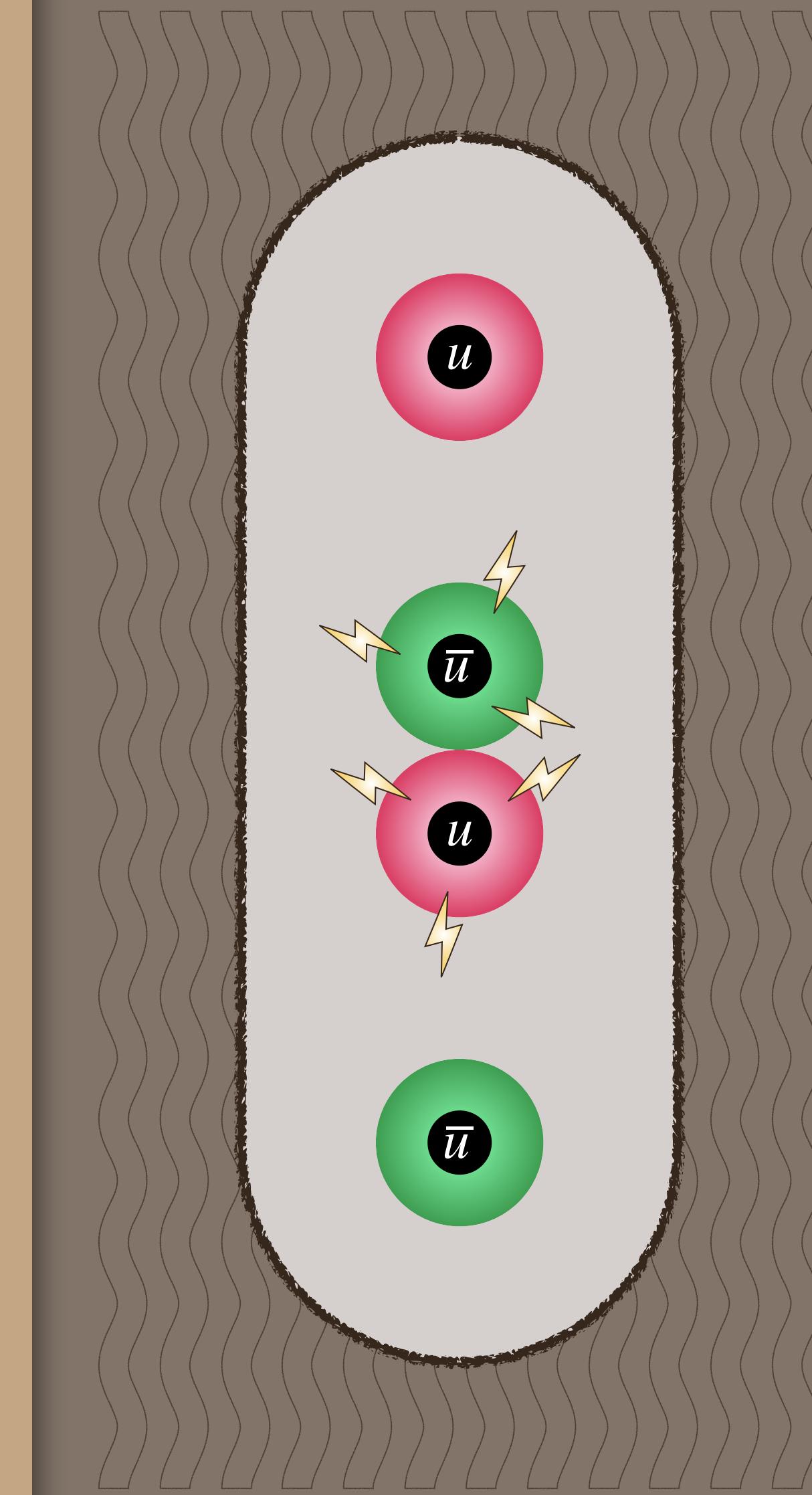
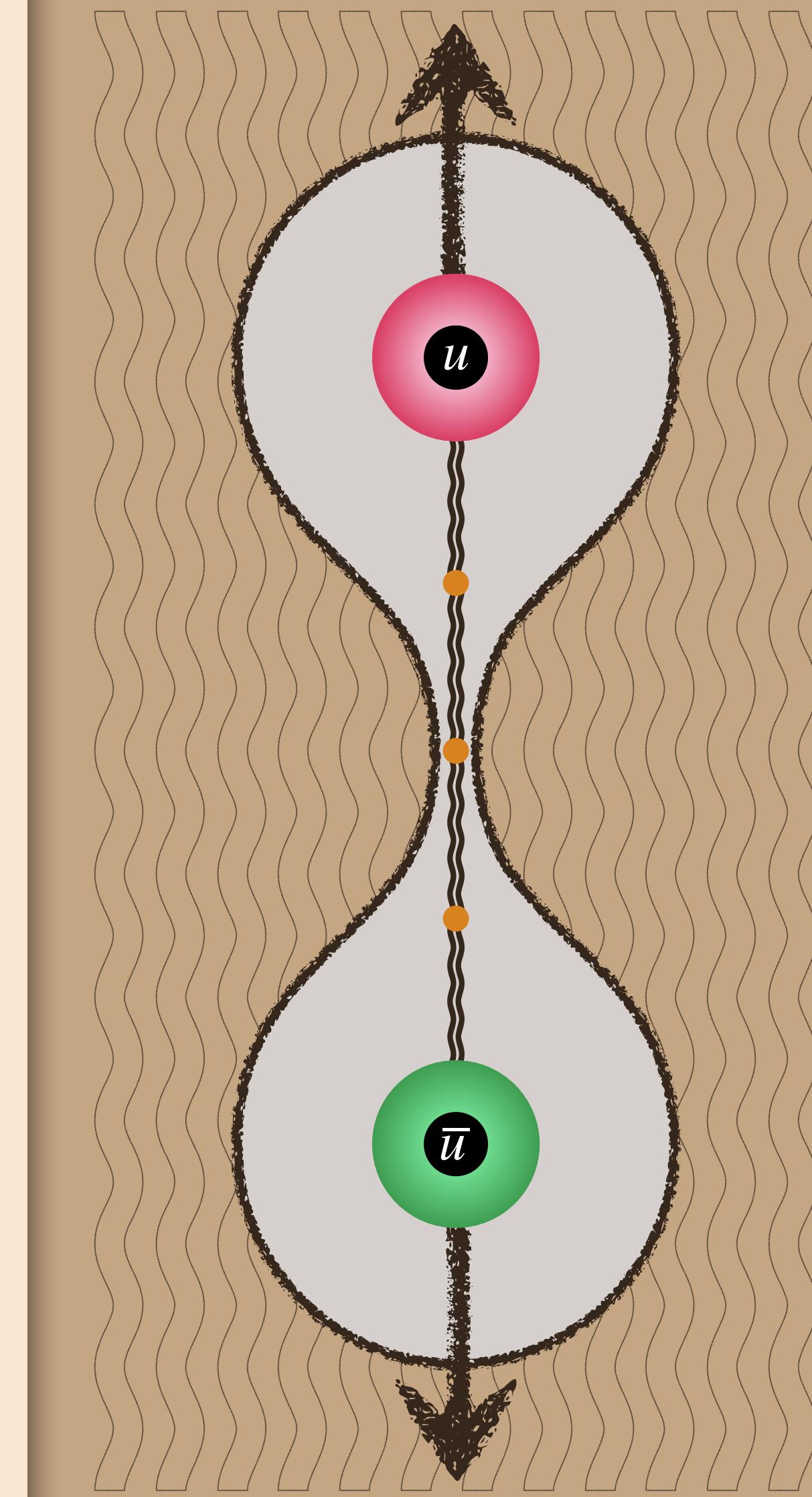
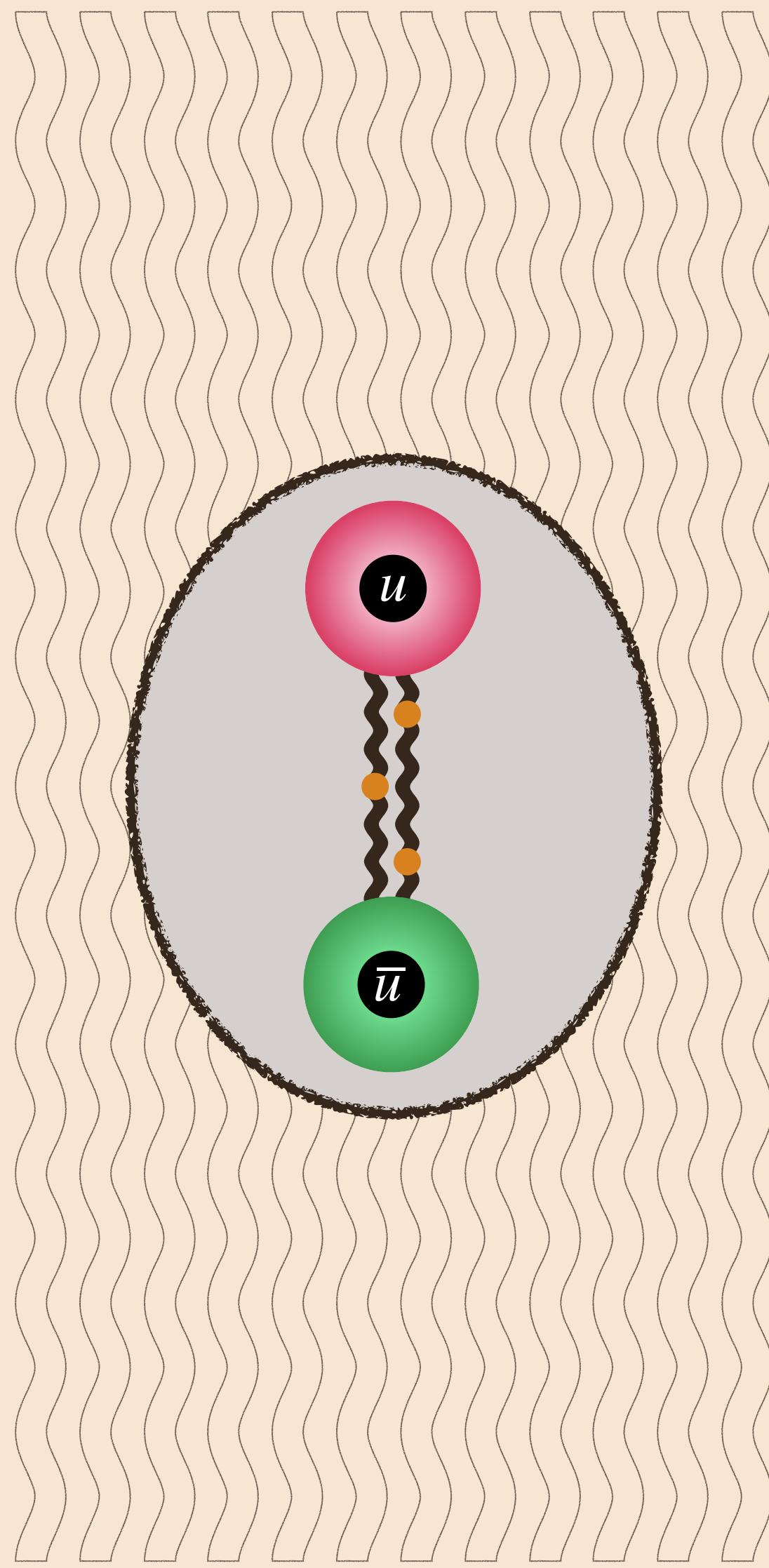
STRONG FORCE

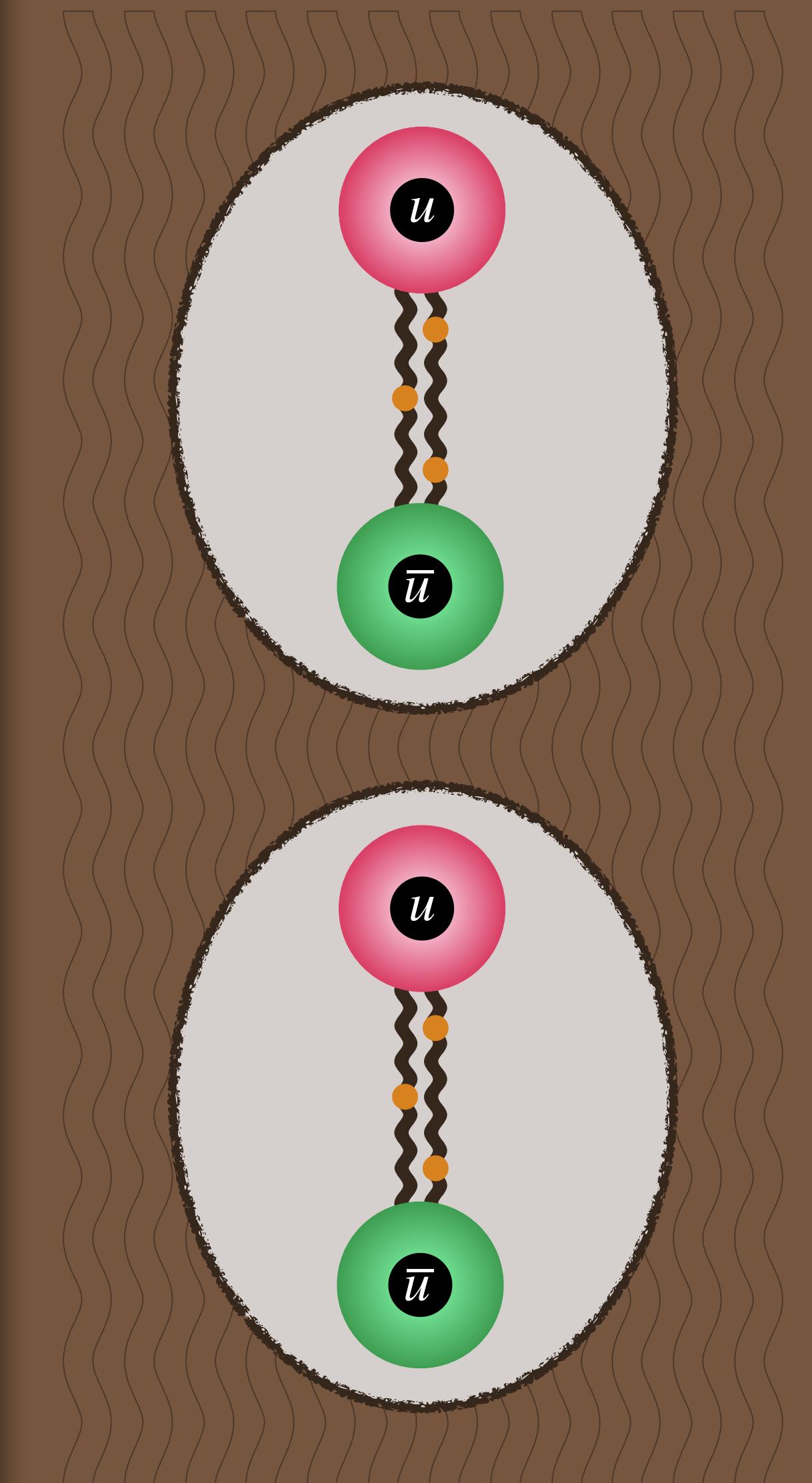
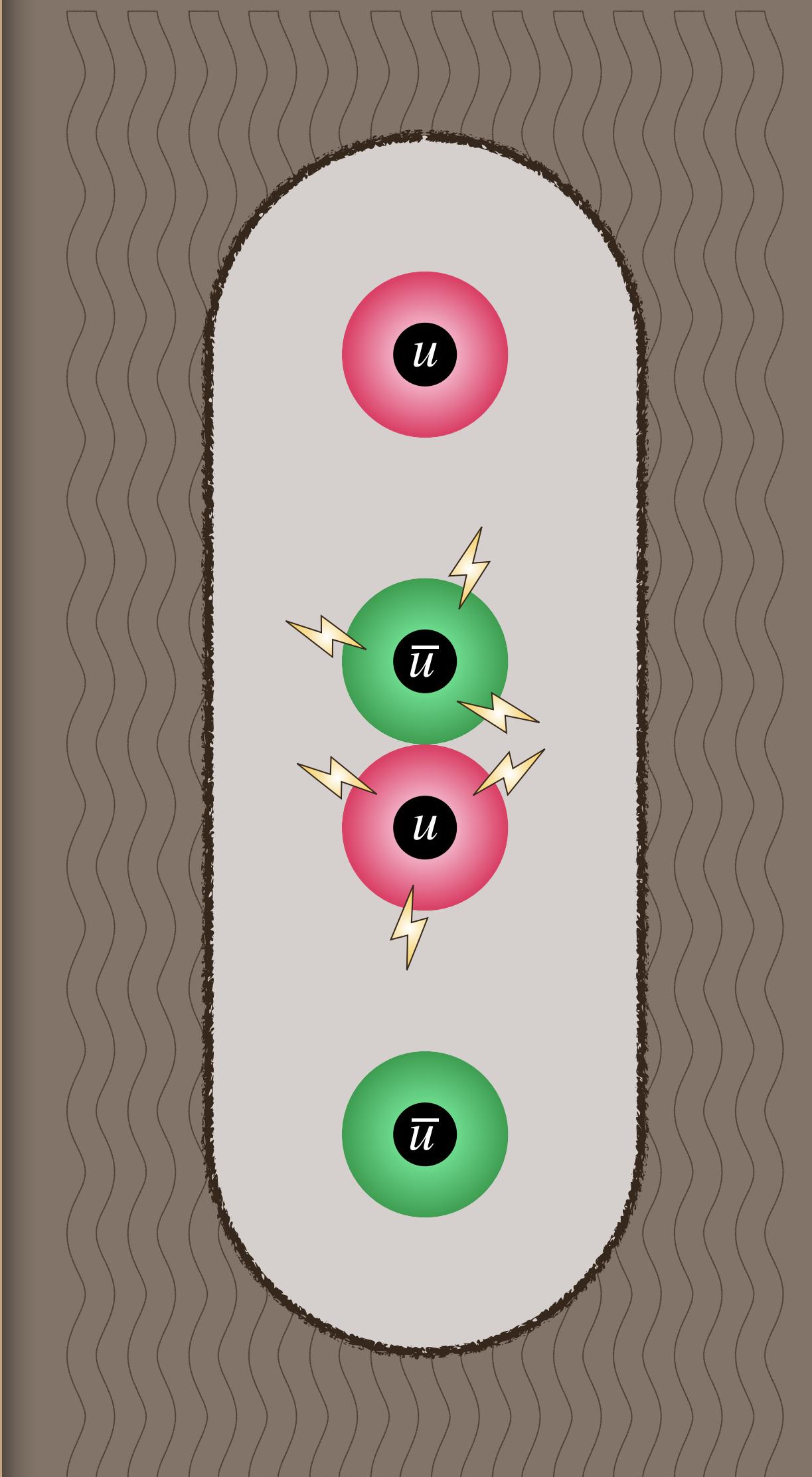
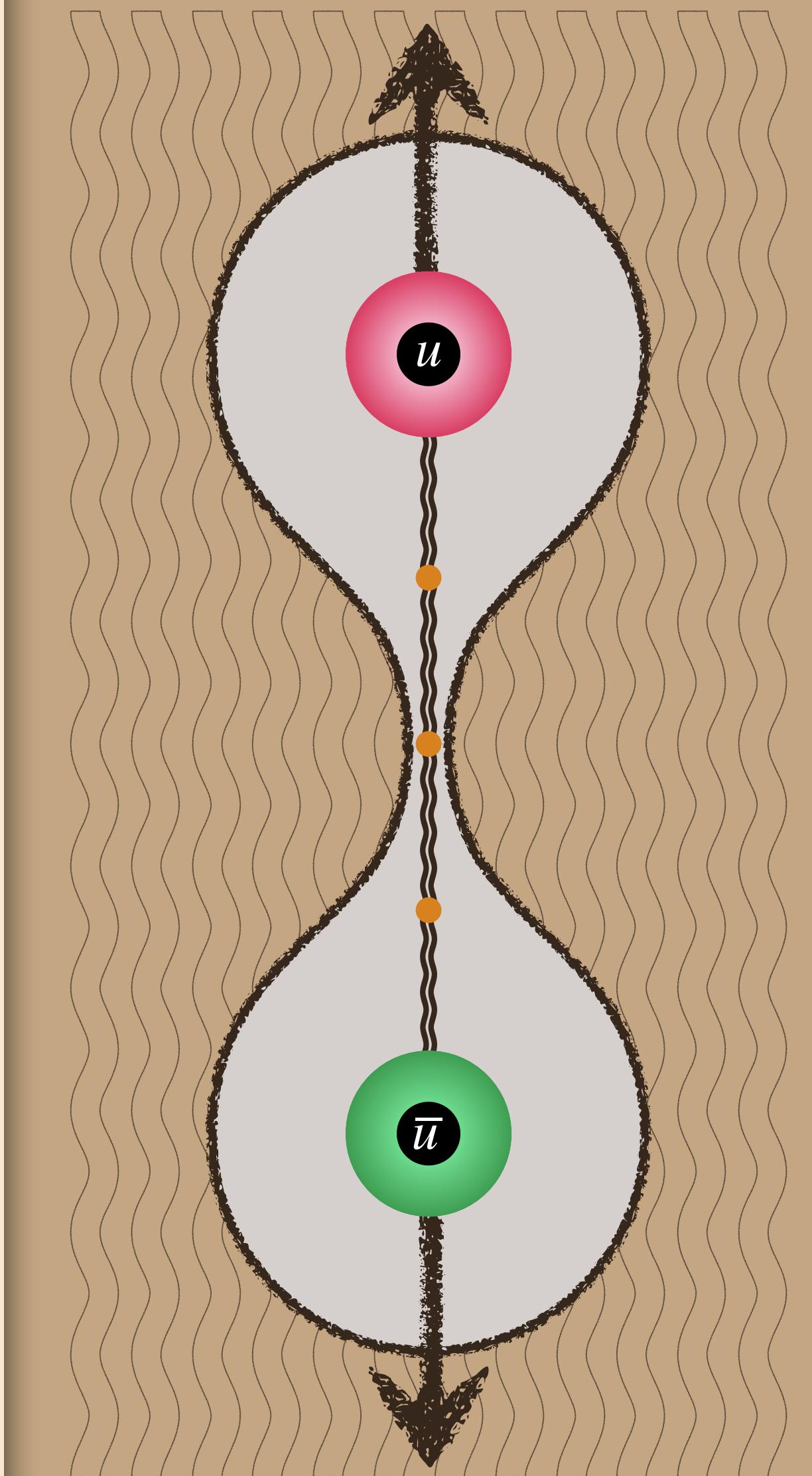
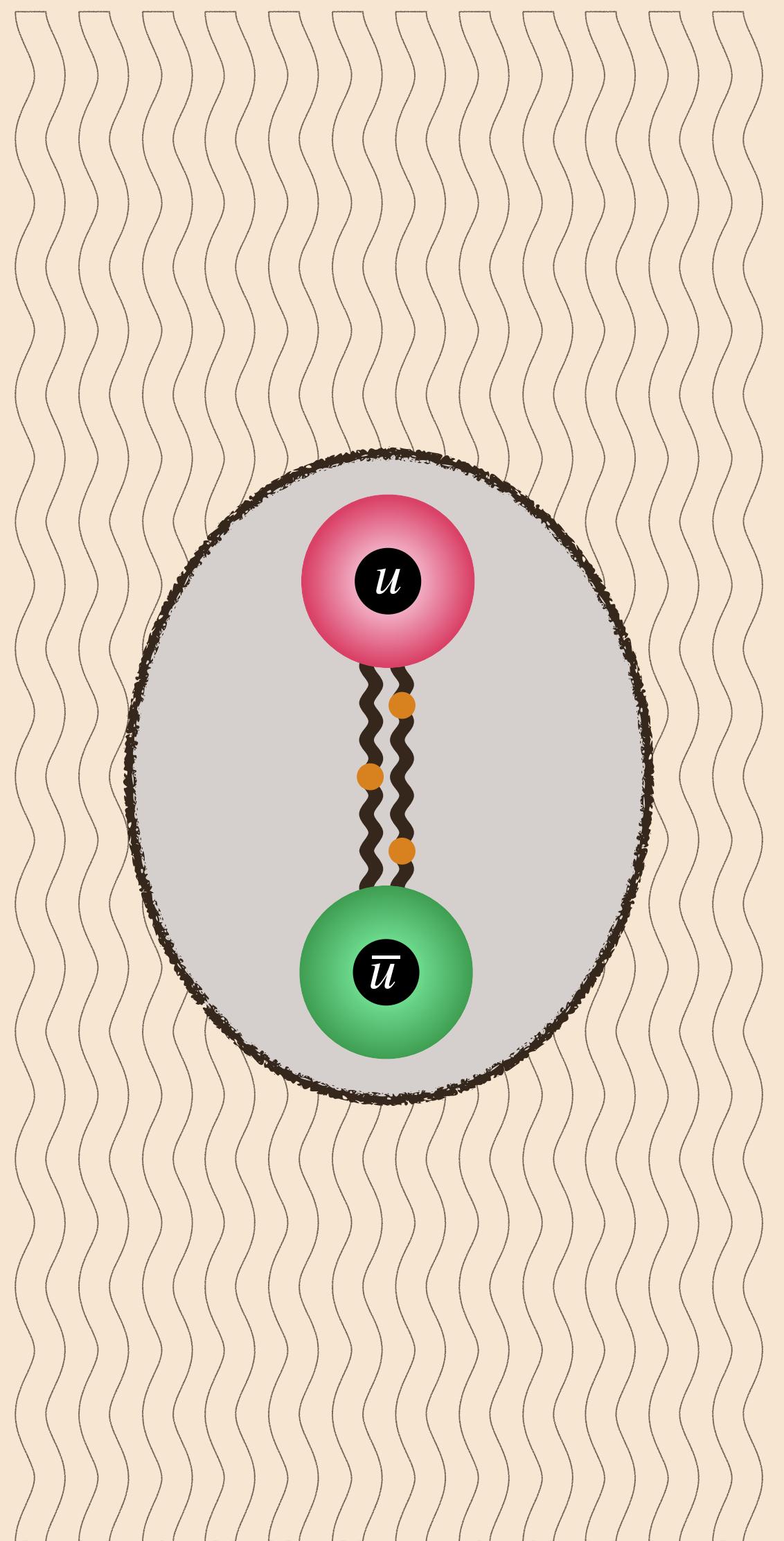


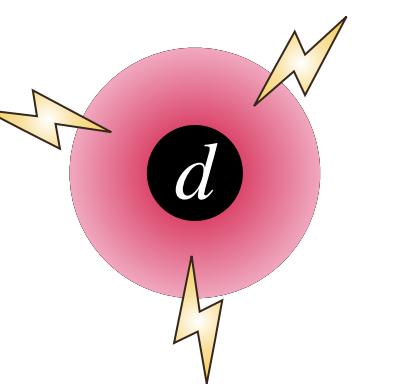






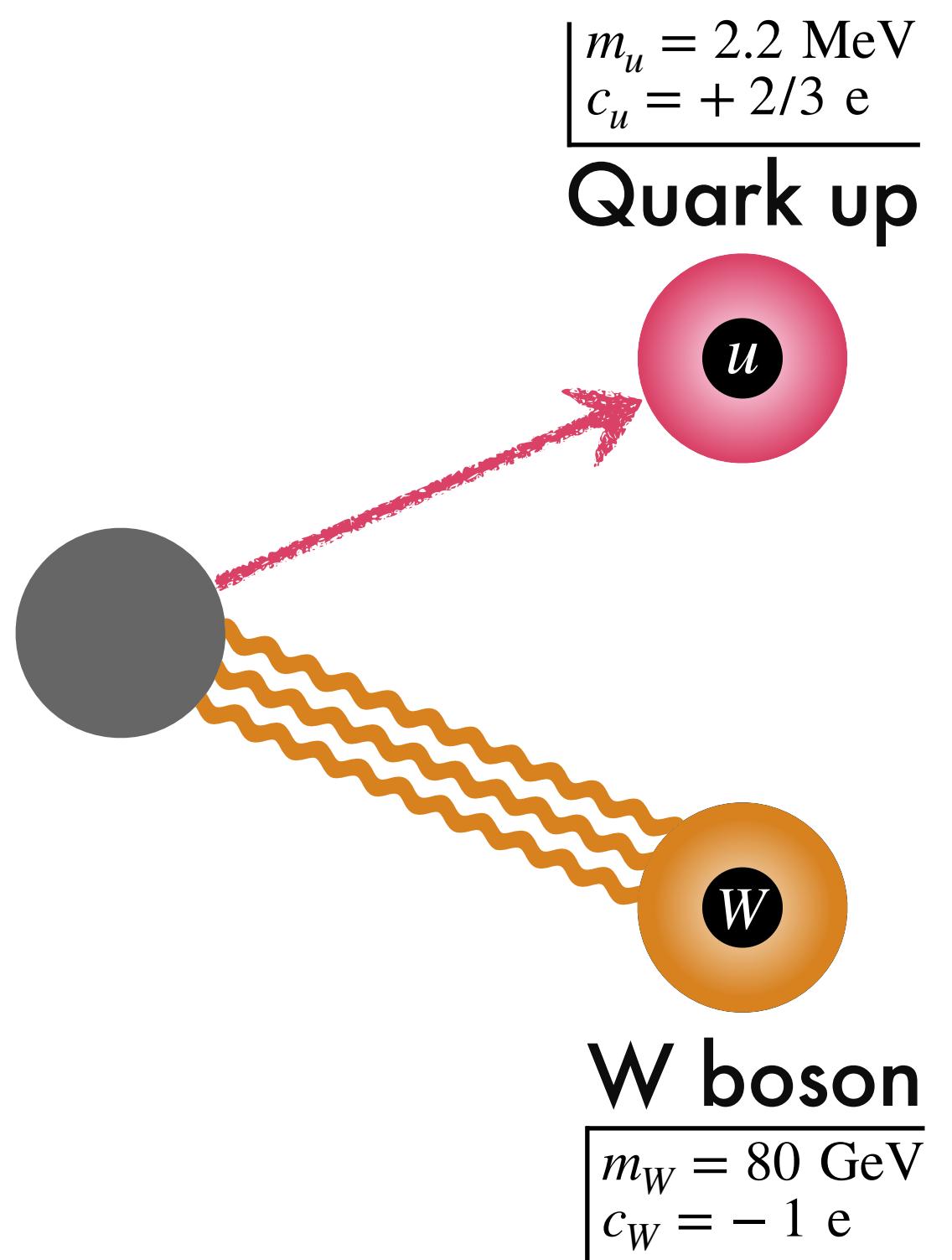


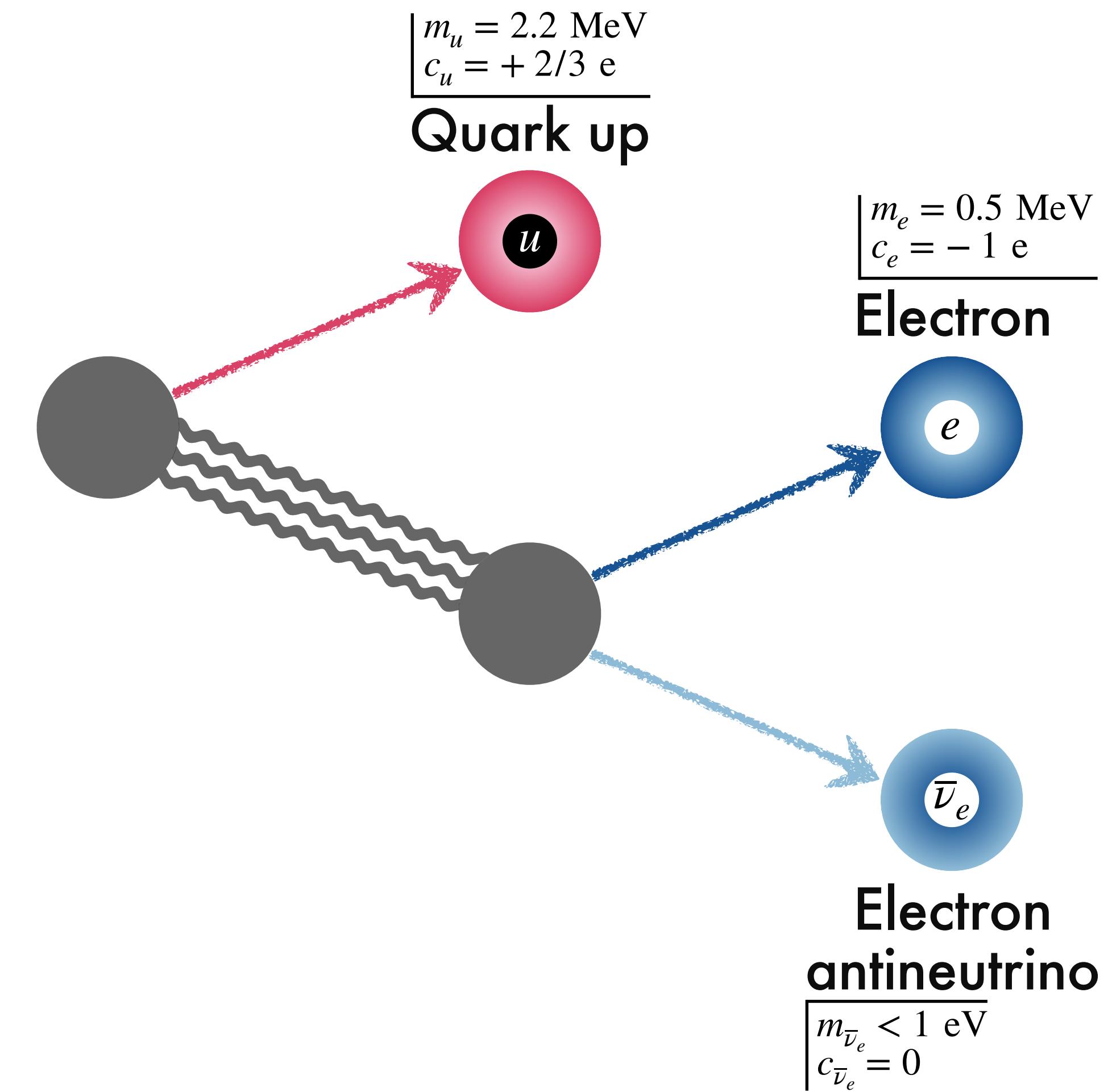


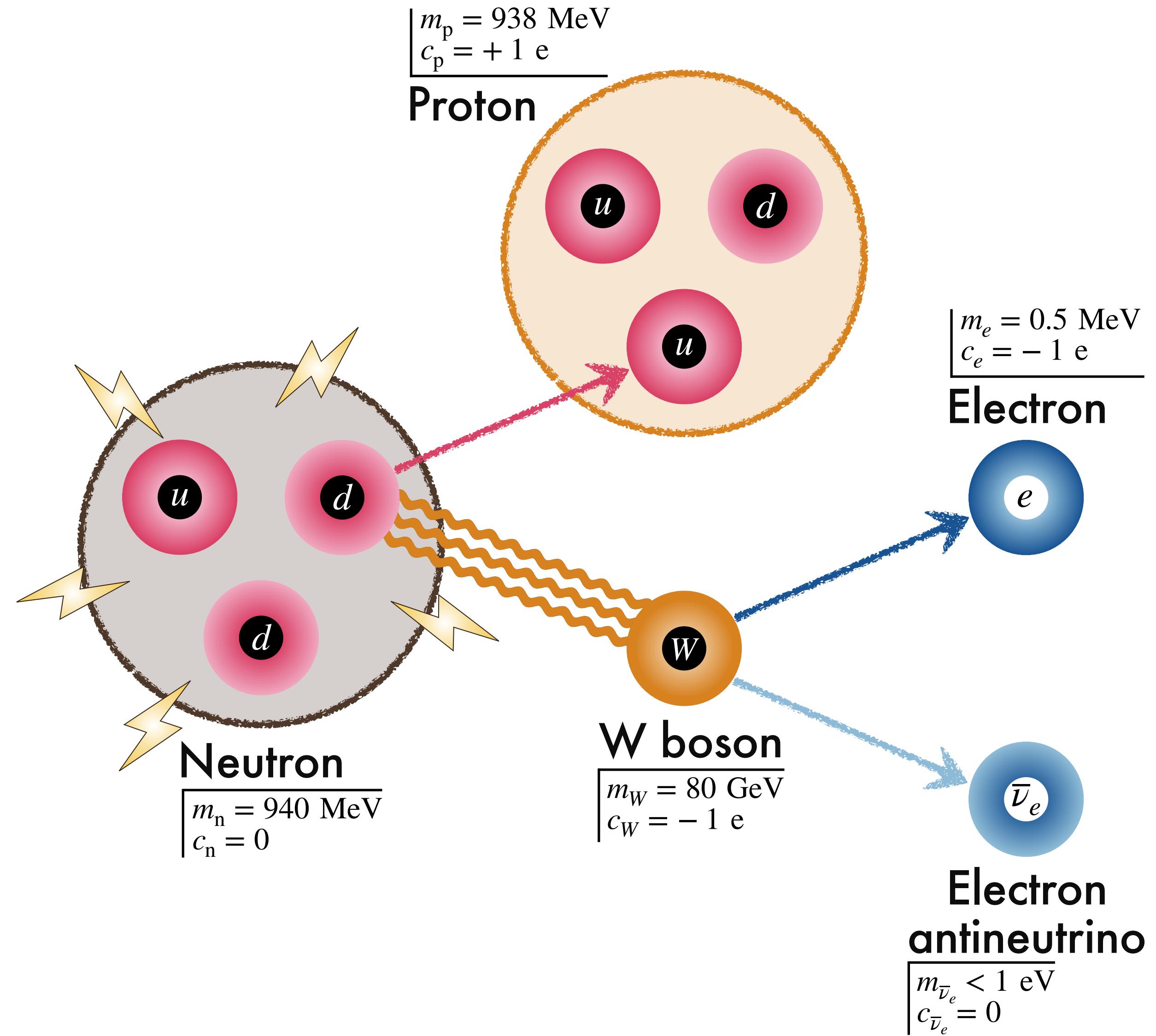


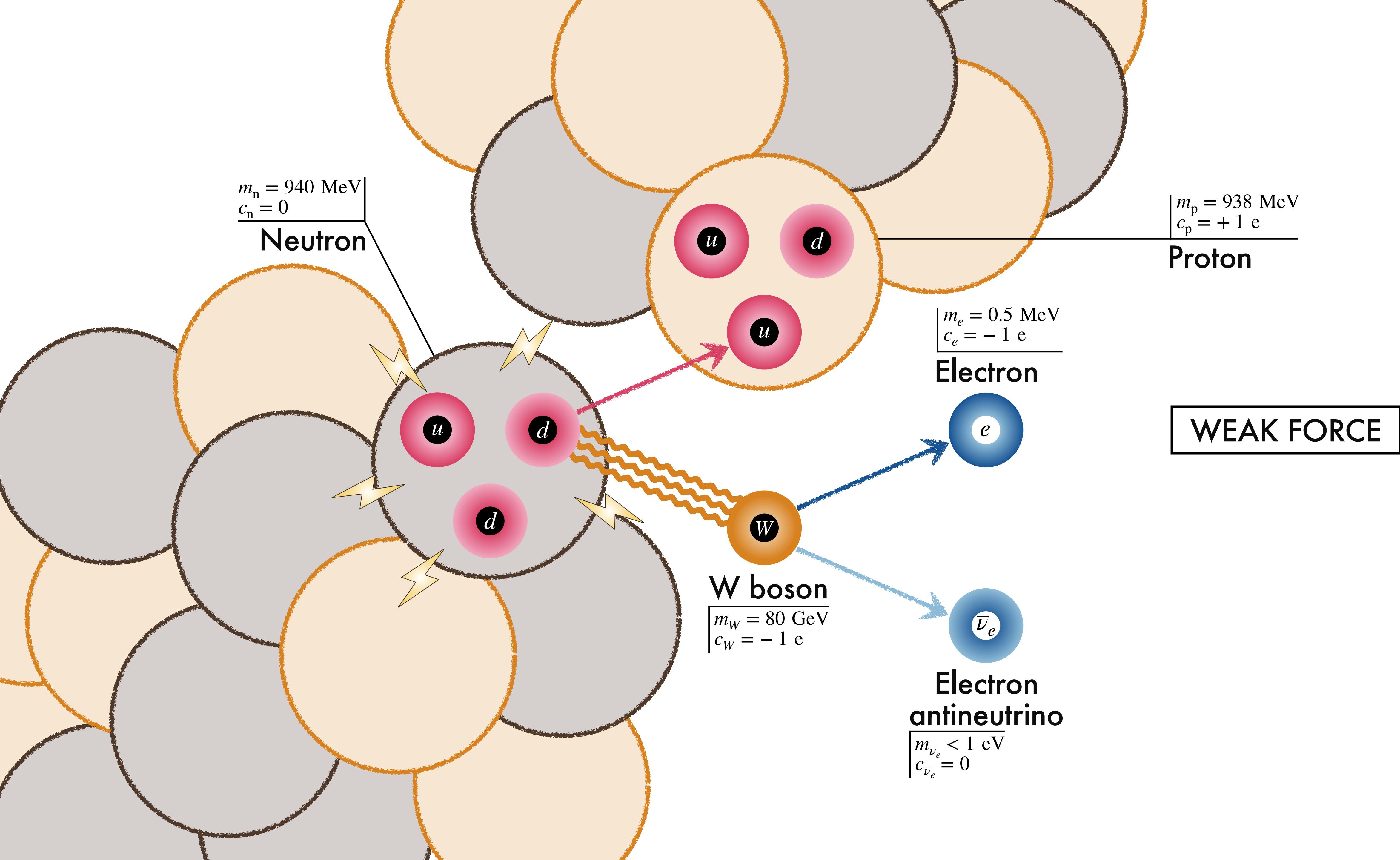
Quark down

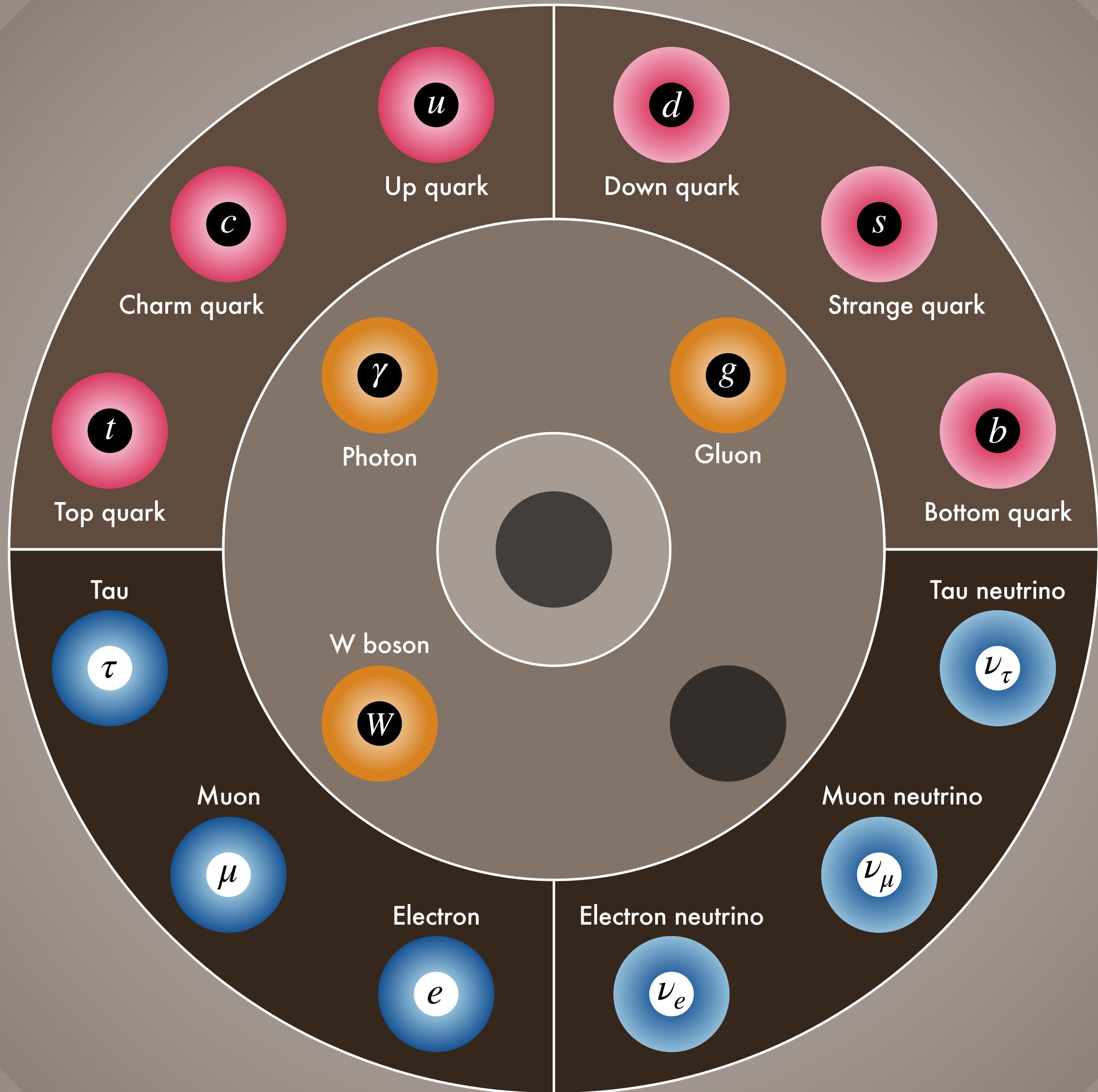
$$\begin{cases} m_d = 4.7 \text{ MeV} \\ c_d = -1/3 \text{ e} \end{cases}$$

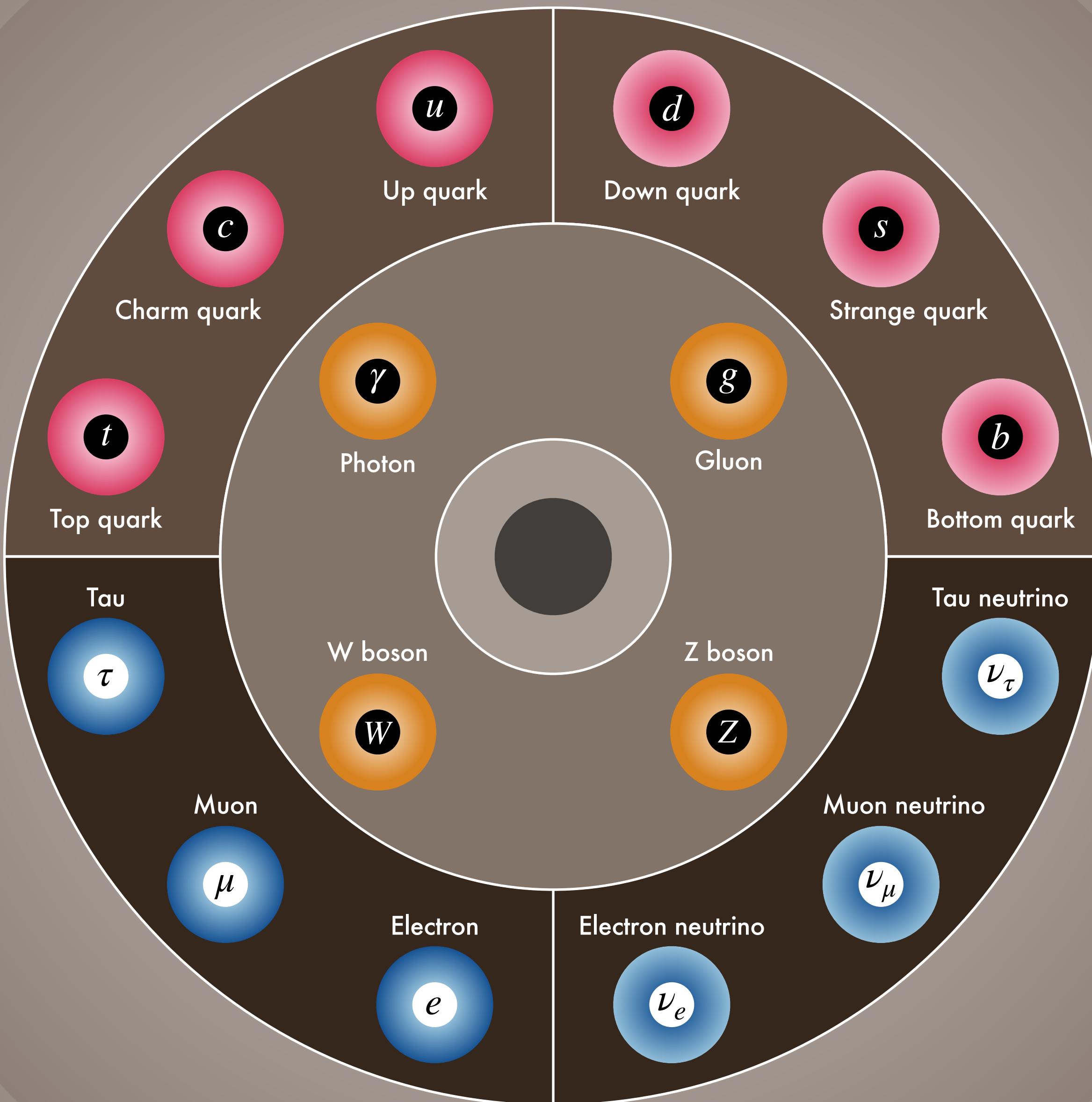




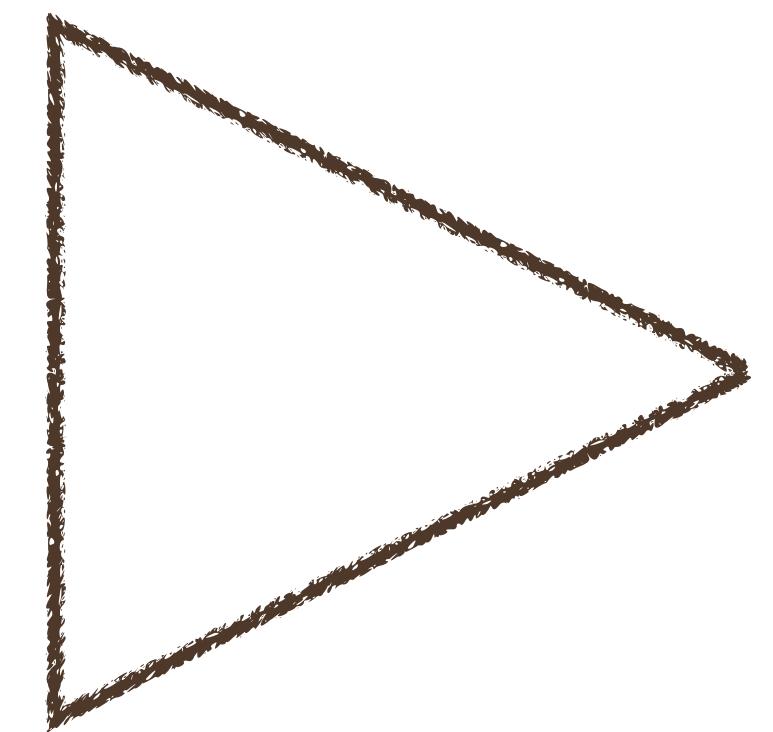
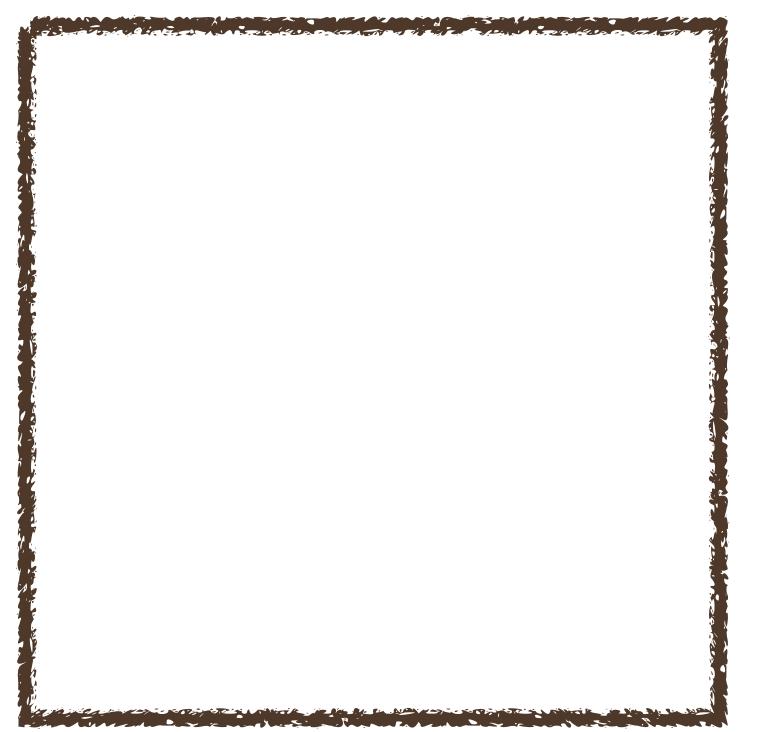


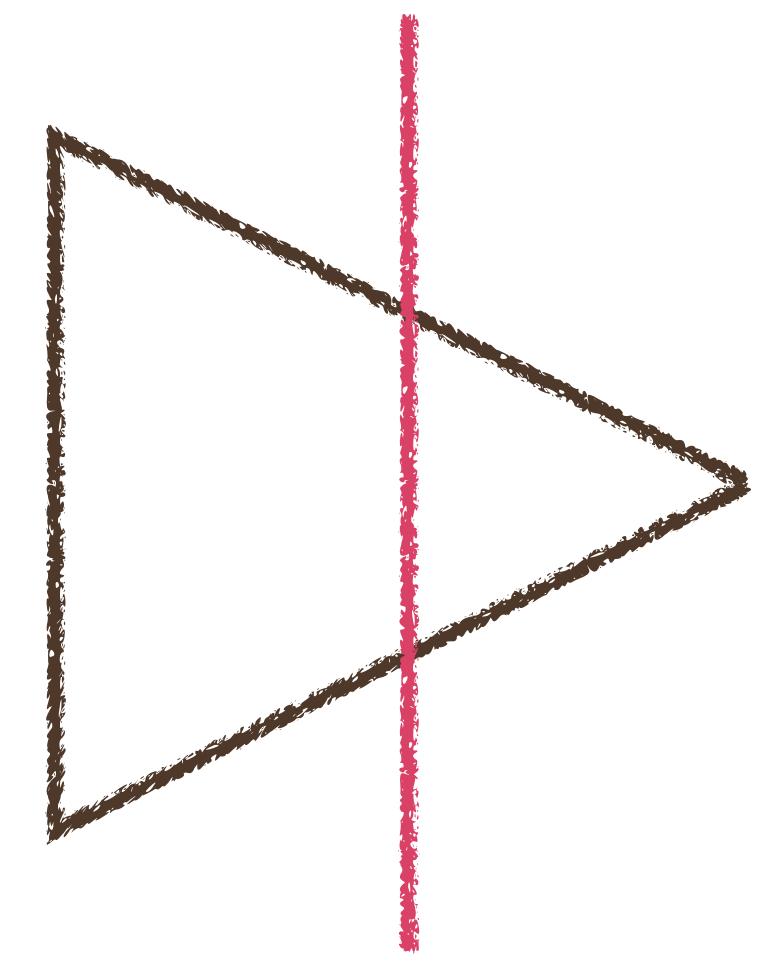
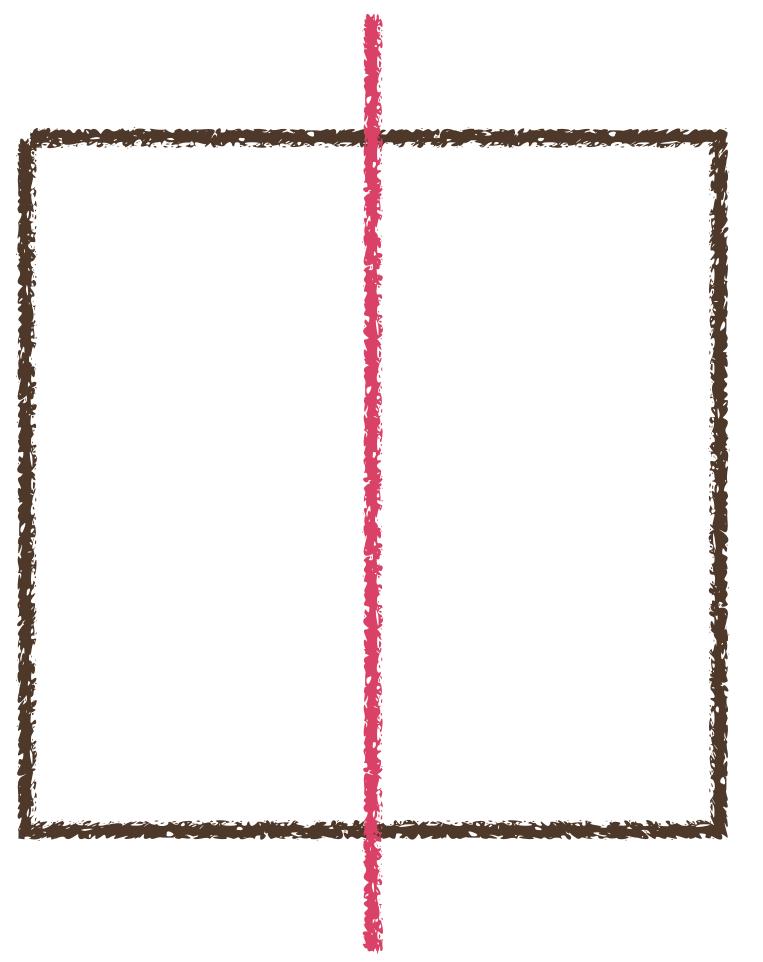






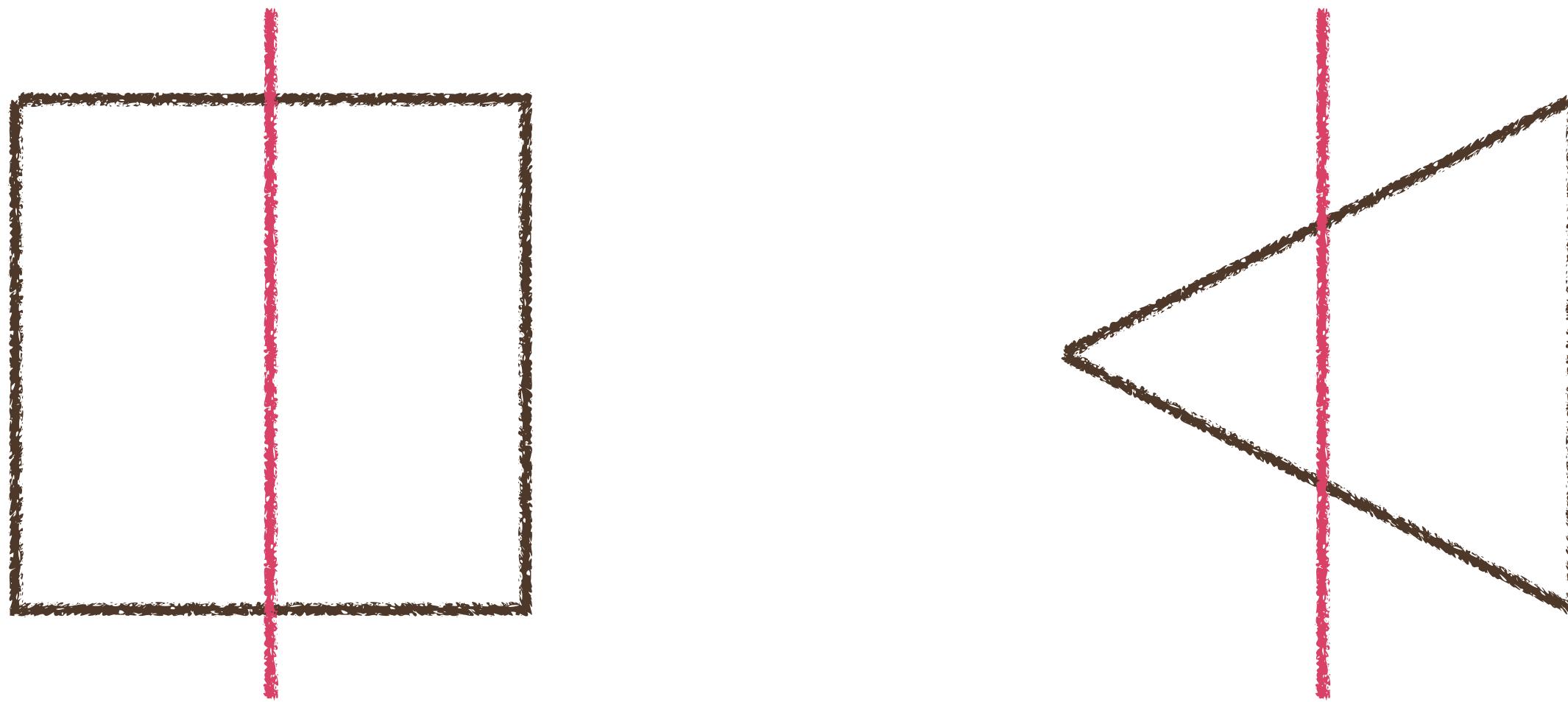
THE GOD PARTICLE





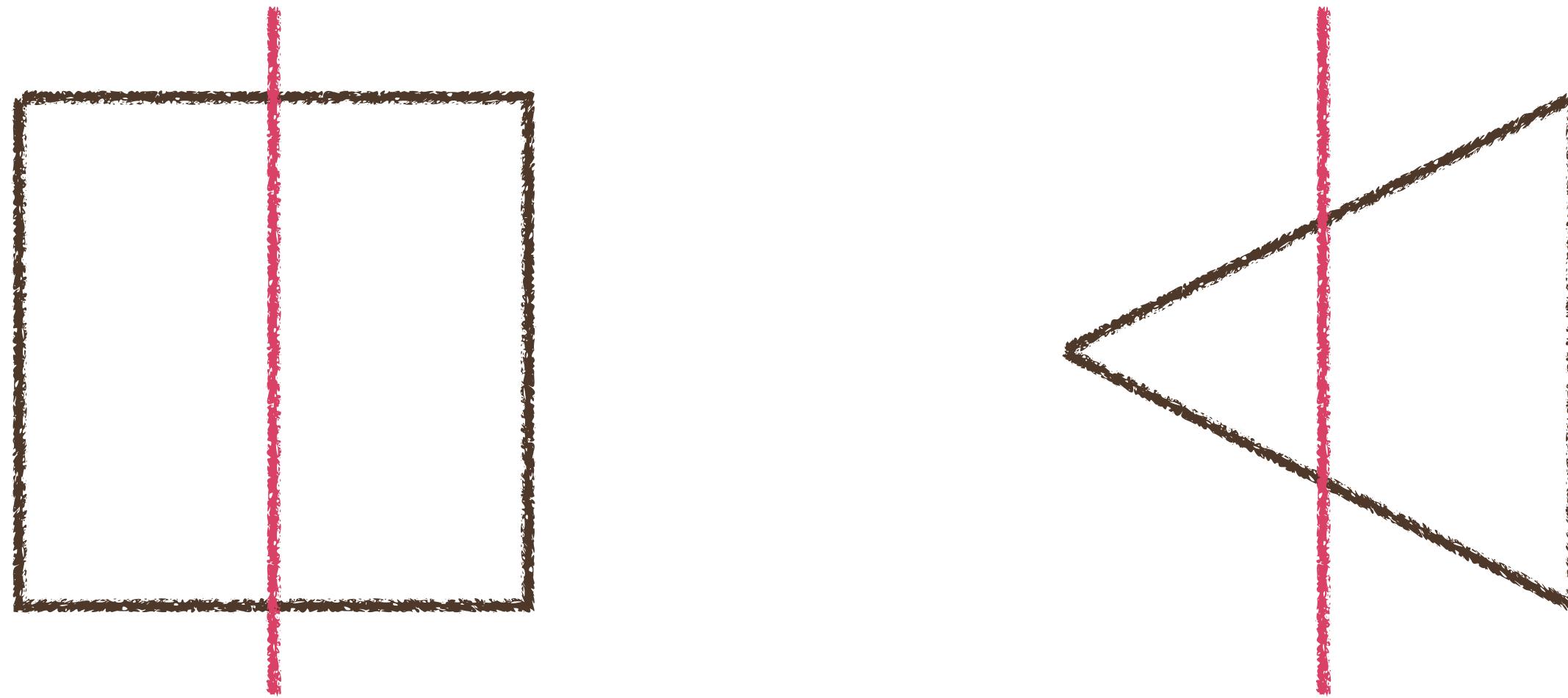
INVERSION

$$x \mapsto -x$$



INVERSION

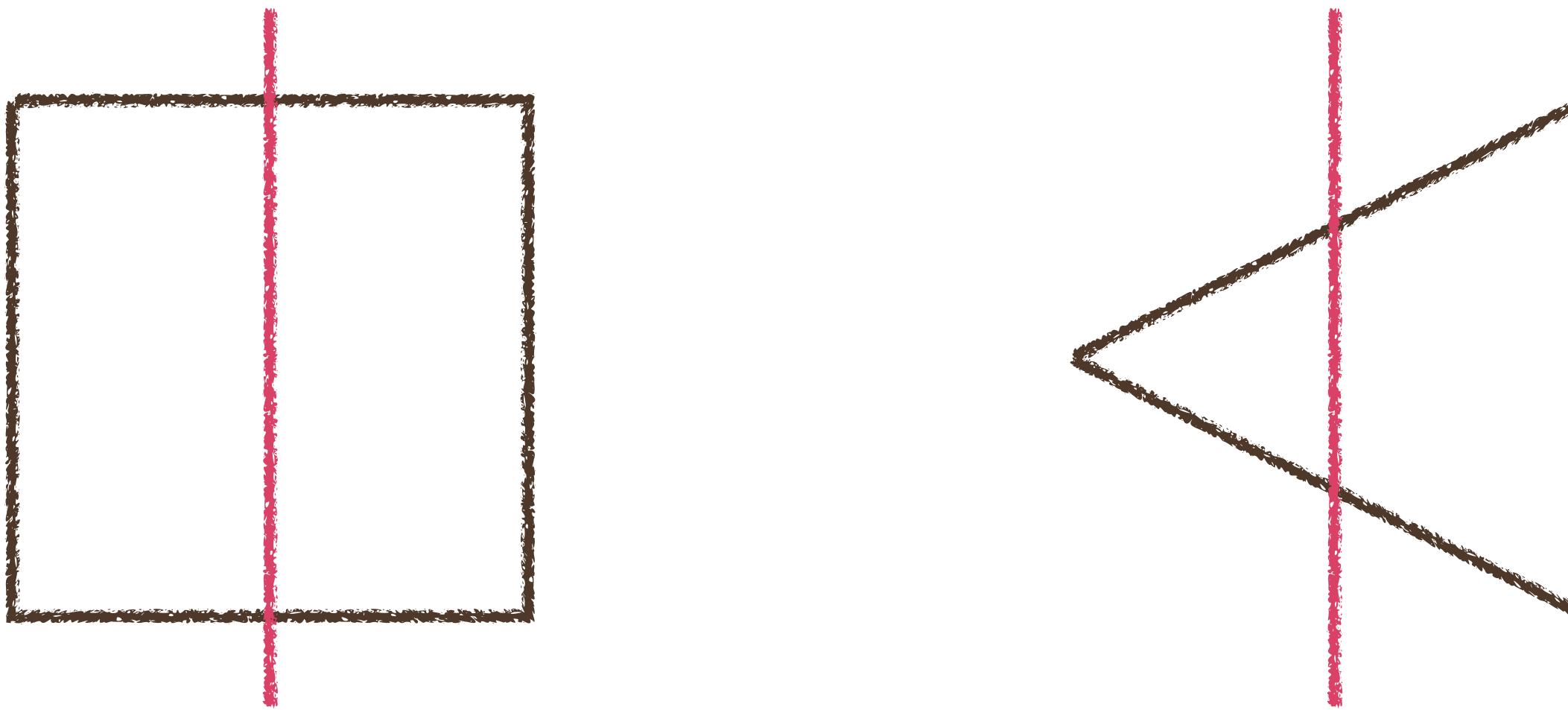
$$x \mapsto -x$$



$$\mathcal{L}(x) = c_1 x^4 + c_2 x^3$$

INVERSION

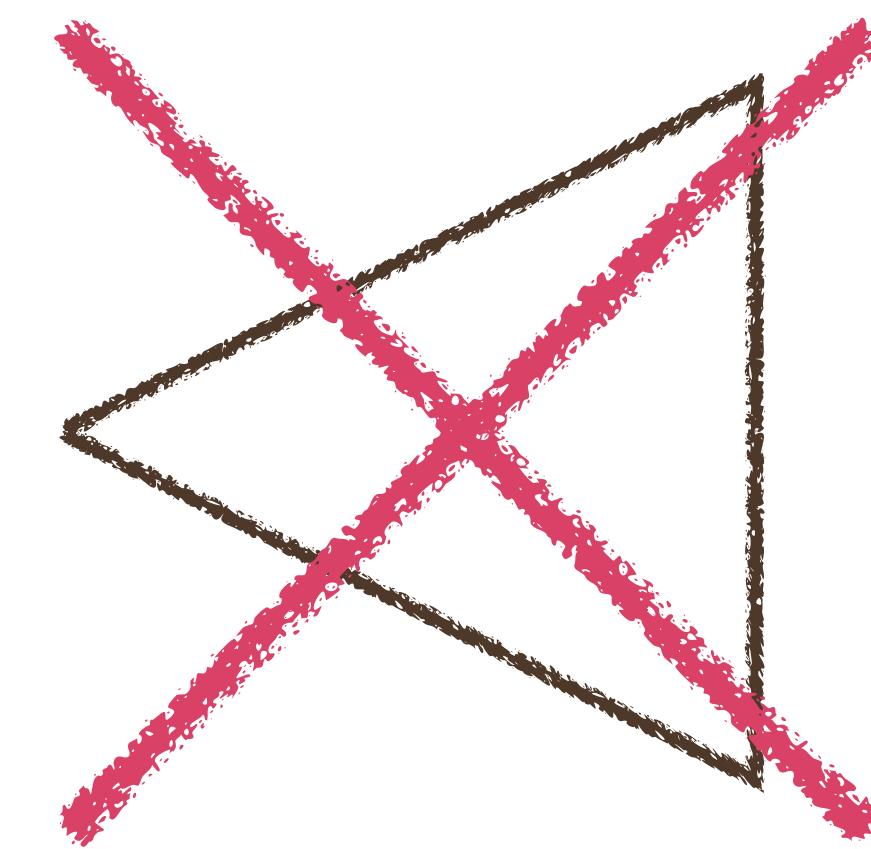
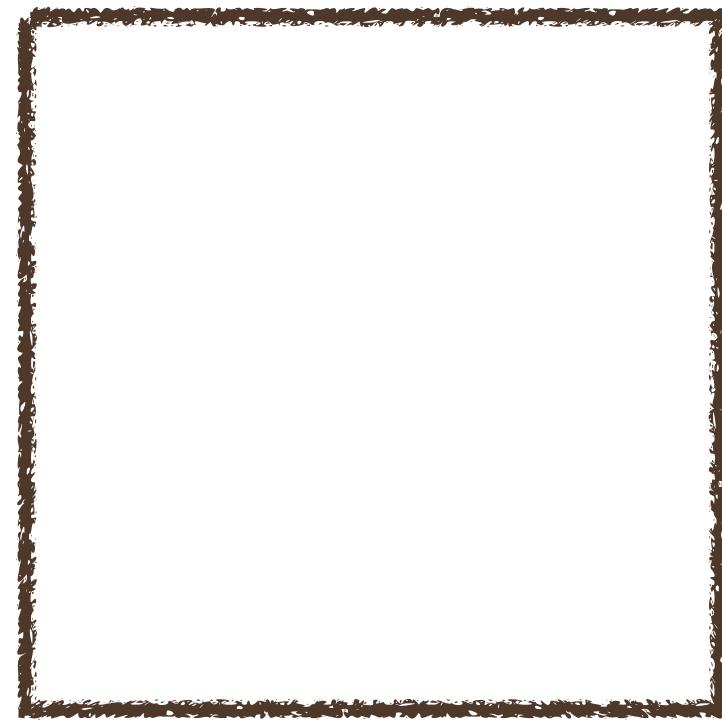
$$x \mapsto -x$$



$$\mathcal{L}(x) = c_1 x^4 + c_2 x^3 \quad \longrightarrow \quad \mathcal{L}(-x) = c_1 x^4 - c_2 x^3$$

INVERSION

$$x \mapsto -x$$



$$\mathcal{L}(x) = c_1 x^4 + \cancel{c_2 x^3} \longrightarrow \mathcal{L}(-x) = c_1 x^4 - \cancel{c_2 x^3}$$

