PRAYAS

JEE 2025

Lecture - 05 | Physics

Modern Physics

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Topics *to be covered*

1. Atomic Collision
2. Energy Level When Mass of Nucleus is Consider
3.
4.

The radiation emitted when an electron jumps from $n = 3$ to $n = 2$ orbit in a hydrogen atom falls on a metal to produce photoelectrons. The electrons from the metal surface with maximum kinetic energy are made to move perpendicular to a magnetic field of (1/320) T in a radius of 10^{-3} m. Find **(a)** the kinetic energy of the electrons, **(b)** work function of the metal, and **(c)** wavelength of radiation.

$$\frac{1240}{\lambda} = 13.6\left(\frac{1}{2^2} - \frac{1}{3^2}\right)$$

$$r = \frac{mv}{qB} = \frac{\sqrt{2m(KE)_{max}}}{qB}$$

$$13.6 \times \left(\frac{1}{2^2} - \frac{1}{3^2}\right) = \phi + (KE)_{max}$$

$$(KE)_{max} = (\quad)\ J$$

Electrons in a hydrogen-like atom ($Z = 3$) make transitions from the fourth excited state to the third excited state and from the third excited state to the second excited state. The resulting radiations are incident on a metal plate and eject photoelectrons. The stopping potential for photoelectrons ejected by shorter wavelength is 3.95 eV.

Calculate the work function of the metal and stopping potential for the photoelectrons ejected by the longer wavelength.

n=5 n=4 n=4 n=3 4 → 3

$$13.6 \times 3^2 \left(\frac{1}{3^2} - \frac{1}{4^2}\right) = \phi + 3.95$$

$$13.6 \times 3^2 \left(\frac{1}{4^2} - \frac{1}{5^2}\right) = \phi + (eV_0)$$


n=5
n=4
n=3
n=2
n=1

A hydrogen-like atom (atomic number Z) is in a higher excited state of quantum number n. This excited atom can make a transition to the first excited state by successively emitting two photons of energies 10.20 eV and 17.00 eV, respectively.

$n = 2$

$(n \longrightarrow 2)$

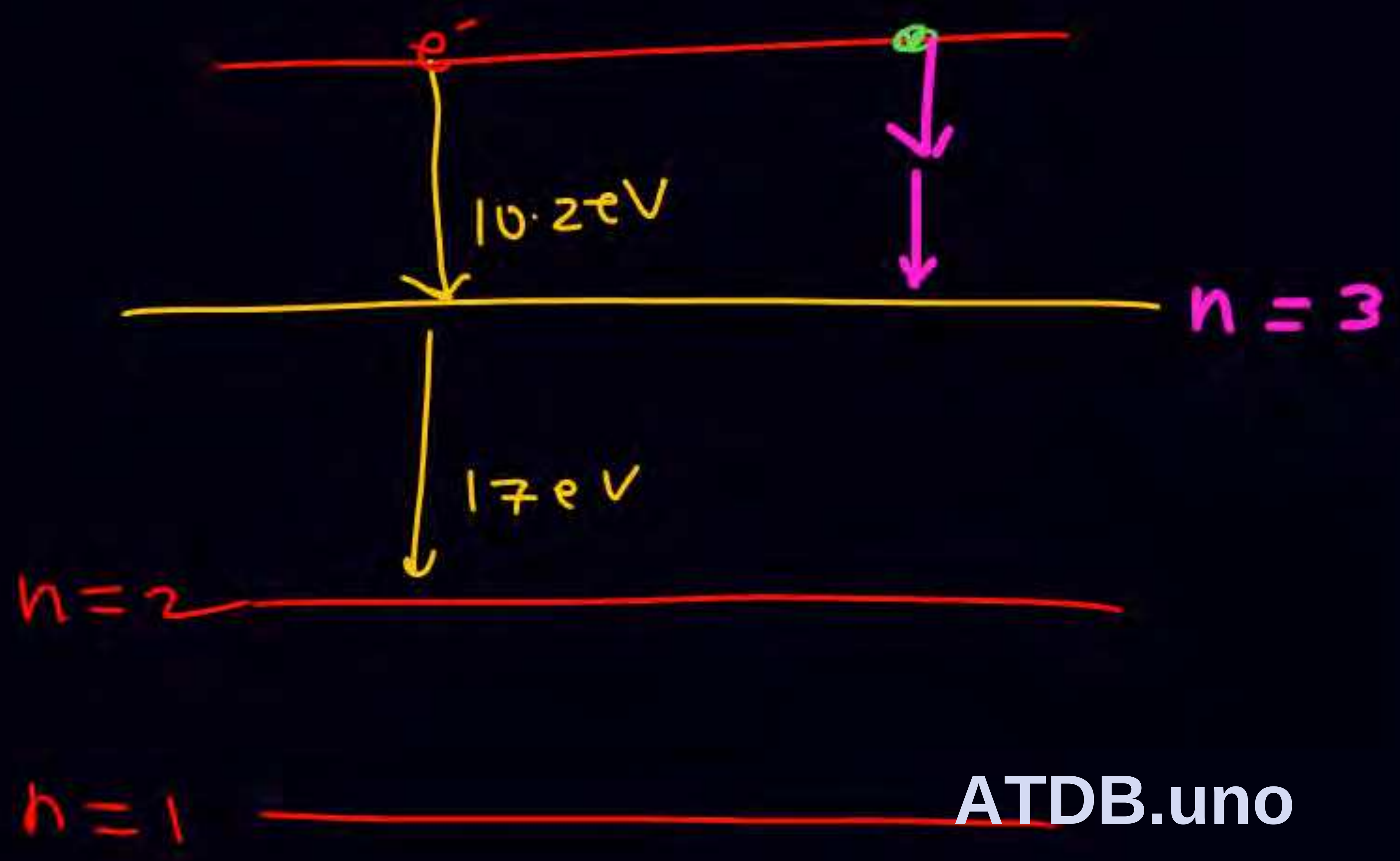
$27.2 = 13.6 Z^2 \left(\frac{1}{2^2} - \frac{1}{n^2}\right)$

$10.2 = 13.6 Z^2 \left(\frac{1}{3^2} - \frac{1}{n^2}\right)$

Alternatively, the atom from the same excited state can make a transition to the second excited state by successively emitting two photons of energies 4.25 eV and 5.954 eV, respectively. Determine the values of n and Z (ionization energy of hydrogen atom = 13.6 eV).

$n \longrightarrow 3$

5.954
4.25
10.204



e⁻
10.2eV
n = 3
17eV
n=2
n=1

A hydrogen-like atom with atomic number Z is found to be in an excited state corresponding quantum number $2n$. It can emit a maximum energy photon of 204 eV. If it makes a transition to quantum state n, a photon of energy 40.8 eV is emitted. Find n, Z and the ground state energy (in eV) for this atom. Also, calculate the minimum energy (in eV) that can be emitted by this atom during de-excitation. Ground state energy of hydrogen atom is – 13.6 eV.

$$40.8 = 13.6 Z^2\left(\frac{1}{n^2} - \frac{1}{(2n)^2}\right)$$

$$204 = 13.6 Z^2\left(\frac{1}{1^2} - \frac{1}{(2n)^2}\right)$$

$$\frac{204 = 13.6\,z^2\left(\frac{1}{1^2} - \frac{1}{(2n)^2}\right)}{40.8 = 13.6\,z^2\left(\frac{1}{n^2} - \frac{1}{(2n)^2}\right)}$$

$$5 = \frac{(4n^2 - 1)}{4n^2} \Big/ \frac{3}{4n^2}$$

$$\frac{1 - \frac{1}{4n^2}}{n^2}$$

$$15 = 4n^2 - 1$$

$$16 = 4n^2$$

$$n = 2$$

Brackett series of lines are produced when electrons excited to high energy levels make transitions to the $n = 4$ level.

(a) Determine the longest wavelength in this series.

(b) Determine the wavelength that corresponds to the transition from $n_f = 6$ to $n_i = 4$.

$(\Delta E)_{min}$

$5 \rightarrow 4$

$13.6 \times 1^2 \left(\frac{1}{4^2} - \frac{1}{5^2}\right)$

Assume that the potential energy of a hydrogen atom in its ground state is zero. Then its energy in the first excited state will be:

A. 23.8eV

B. 27.5eV

C. 30.4eV

D. 34.8eV

$Z = 1$

हमने जो पढ़ा है

$n = \infty$ पर $PE = 0$

$n = 2$

$TE = -3.4$ $KE = 3.4$, $PE = -6.8$

$KE = 3.4$

$PE_{नई} = -6.8 + 27.2 = 20.4$

$\rightarrow T.E = 23.8$

$n = 1$

$TE = -13.6$, $KE = 13.6$, $PE = -27.2$

$PE = 0$, $KE = 13.6$ $\rightarrow T.E = 13.6$

$+27.2$

$Z = 1$

Let P.E at $n = 2$ is taken as zero find T.E at $n = 1$

हमने जो पढ़ा है

$n = \infty$ पर $PE = 0$

पुराना ⇓	नया ⇓
$TE = -3.4$, $KE = 3.4$, $PE = -6.8$	$PE = 0$, $KE = 3.4$
$TE = -13.6$, $KE = 13.6$, $PE = -27.2$ ($n=1$)	$PE = -27.2 + 6.8$, $KE = 13.6$

A doubly ionized lithium atom is hydrogen-like with atomic number 3. Find the wavelength of the radiation required to excite the electron in Li^{++} from the first to third Bohr orbit. The ionization energy of the hydrogen atom is 13.6 eV.

EXAMPLE 3 Find the kinetic energy, potential energy and total energy in first and second orbit of hydrogen atom if potential energy in first orbit is taken to be zero.

26. An electron in a hydrogen atom undergoes a transition from an orbit with quantum number n_i to another with quantum number n_f. V_i and V_f are respectively the initial and final potential energies of the electron. If $\frac{V_i}{V_f} = 6.25$, then the smallest possible n_f is.

एक हाइड्रोजन परमाणु का एक इलेक्ट्रॉन n_i क्वांटम संख्या (quantum number) वाले कक्ष से n_f क्वांटम संख्या (quantum number) के कक्ष में प्रवेश करता है। V_i तथा V_f प्राथमिक एवं अंतिम स्थितिज उर्जाएं है। यदि $\frac{V_i}{V_f} = 6.25$ तब n_f की न्यूनतम सम्भावी संख्या (smallest possible n_f) है। [JEE Advanced-2017]

$PE \propto \frac{Z^2}{n^2}$

$\frac{(PE)_i}{(PE)_f} = \left(\frac{n_f}{n_i}\right)^2 = 6.25$

$\frac{n_f}{n_i} = 2.5$

$n_f = 2.5\, n_i$

$n_f = 5$ $n_i = 2$

Ans. 5

29. Consider a hydrogen-like ionized atom with atomic number Z with a single electron. In the emission spectrum of this atom, the photon emitted in the n = 2 to n = 1 transition has energy 74.8 eV higher than the photon emitted in the n = 3 to n = 2 transition. The ionization energy of the hydrogen atom is 13.6 eV. The value of Z is.............. .

$$Z^2 13.6\left(\frac{1}{2^2}-\frac{1}{1^2}\right) - Z^2 13.6\left(\frac{1}{3^2}-\frac{1}{2^2}\right) = 74.8$$

[JEE Advanced-2018]

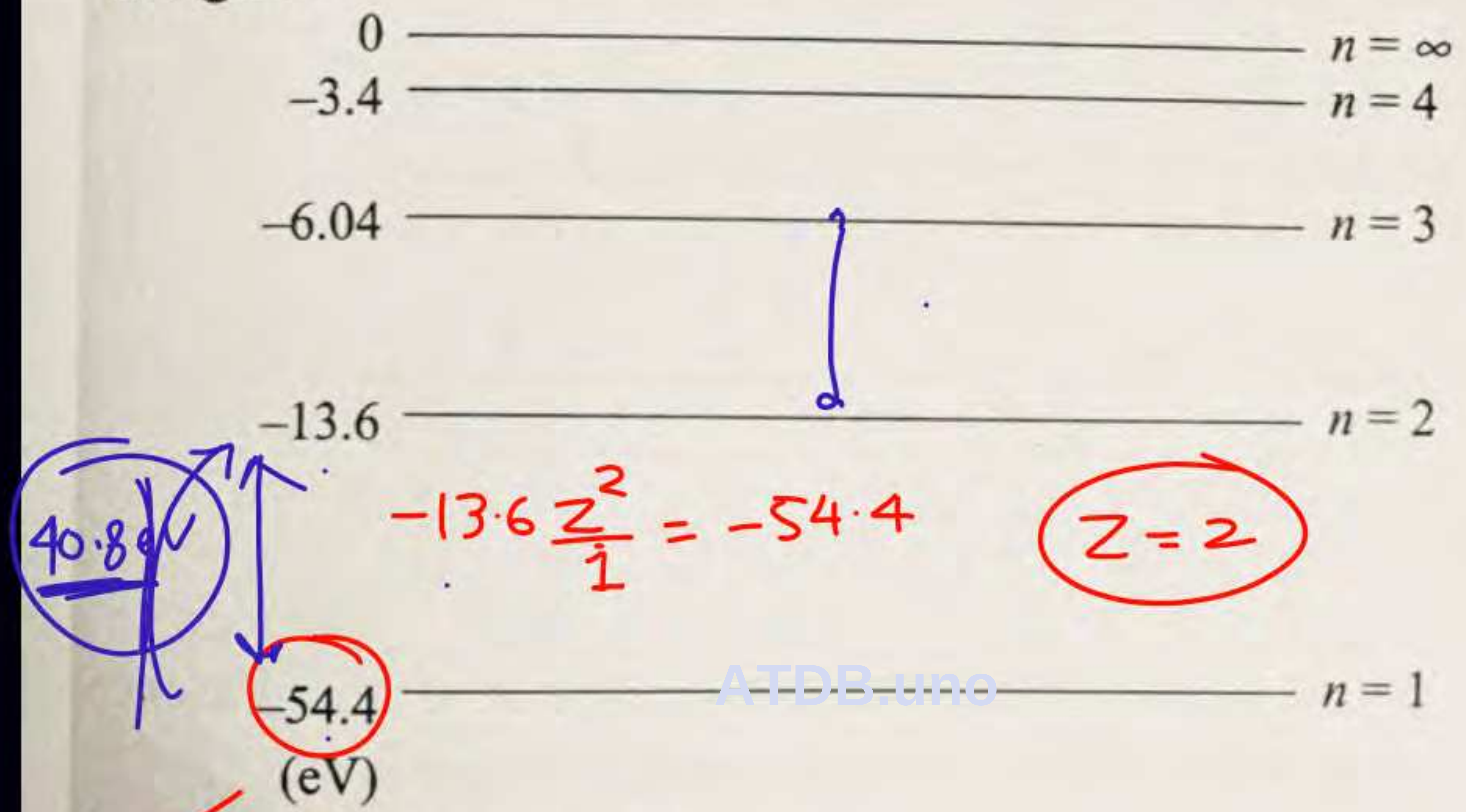
Ans. 3 [3,3]

11. In a photoelectric setup, the radiations from the Balmer series of hydrogen atom are incident on a metal surface of work function 2eV. The wavelength of incident radiations lies between 450 nm to 700 nm. Find the maximum kinetic energy of photoelectron emitted. (Given hc/e = 1242 eV-nm).

हाइड्रोजन परमाणु की बॉमर श्रेणी से सम्बन्धित विकिरणों की तरंगदैर्ध्य जो 450 nm तथा 700 nm के परास में हैं, एक धातु सतह से फोटो इलेक्ट्रॉन उत्सर्जित करने के लिए प्रयोग किये जाते हैं। धातु का कार्य फलन 2eV है। उत्सर्जित होने फोटो-इलेक्ट्रॉन की अधिकतम गतिज ऊर्जा ज्ञात करो। (दिया है : hc/e = 1242 eV-nm) [JEE-2004]

Ans. 0.55 eV

The energy level diagram for a hydrogen-like atom is shown in figure.



(a) Find the value of Z.

(b) If initially the atom is in the ground state, then

(i) determine its first excitation potential, and

(ii) determine its ionization potential.

(c) Can it absorb a photon of 42 eV?

(d) Can it absorb a photon of 56 eV?

(e) Calculate the radius of its first Bohr orbit.

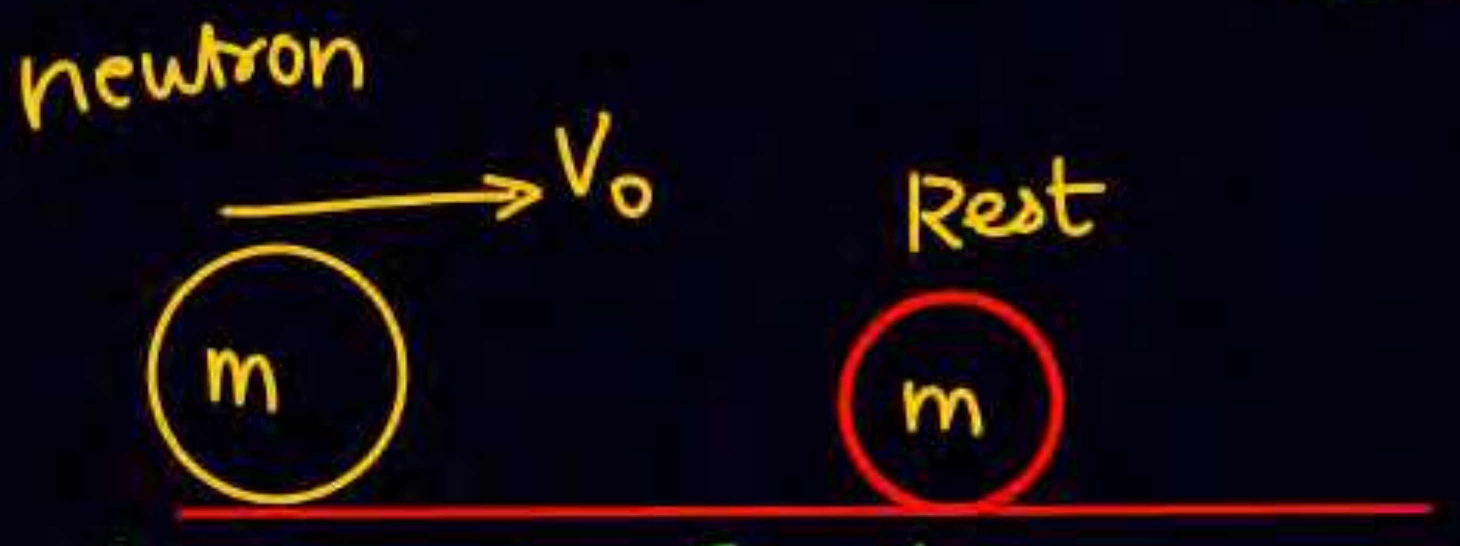
(f) Calculate the kinetic energy and potential energy of an electron in the first orbit.

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

$$e = \frac{v_2 - v_1}{u_1 - u_2}$$

$$|\Delta KE| = \frac{1}{2}\mu u_{rel}^2 (1-e^2) = \frac{1}{2}\frac{m_1m_2}{m_1+m_2}\cdot u_{rel}^2(1-e^2)$$

Atomic Collision



$(KE)_i = \frac{1}{2}mV_0^2 = K$

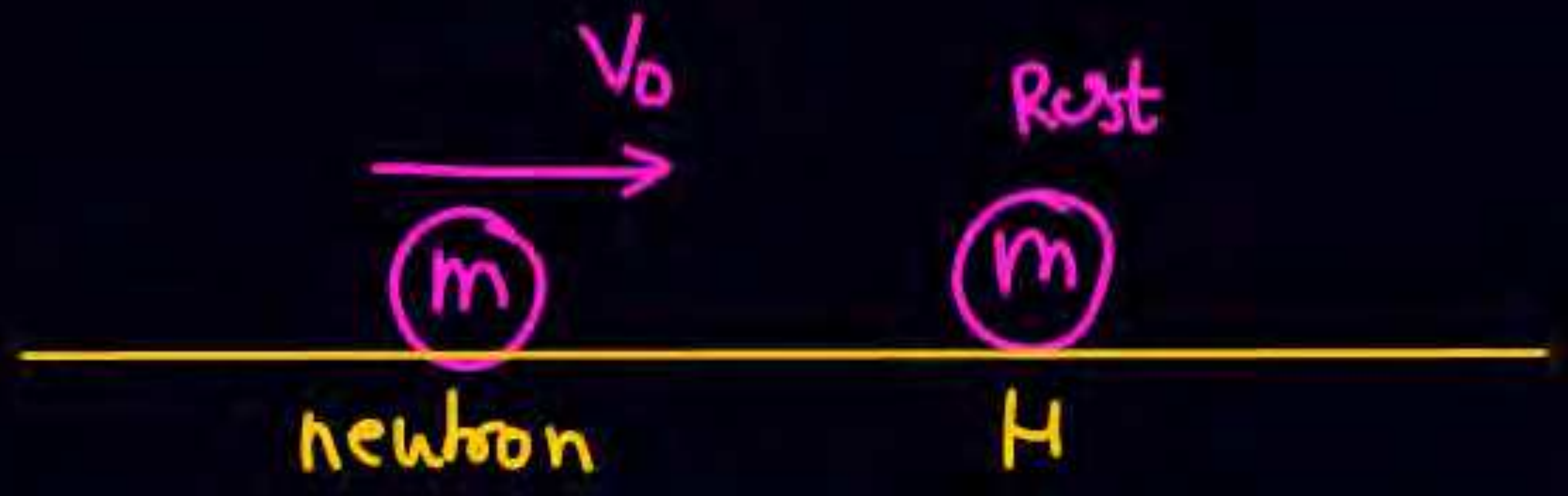
$(\Delta KE)_{loss} = \frac{1}{2}\mu u_{rel}^2 (1-e^2) \equiv$ (com में)

$\Delta(KE)_{max} \equiv$ loss max possible $\equiv$ when $e=0$ $\Longrightarrow \frac{1}{2}\frac{mm}{m+m} V_0^2 (1-0^2) = \frac{1}{2}\left(\frac{1}{2}mV_0^2\right) = \frac{K}{2}$

If

(a) $\frac{K}{2} < 10.2 \Rightarrow e = 1$

$K < 20.4 \Rightarrow$ elastic Collision



* max possible loss in K.E. $= \frac{K}{2}$ (for $e = 0$)

* $0 \le (KE)_{loss} \le (KE)_{max}$

* If $\frac{K}{2} < 10.2 \Rightarrow e = 1$

$K < 20.4$ eV

* SKE काम का है =

Q find possible value of e for following cases

① $K = 10\ eV \Rightarrow e = 1$

② $K = 20\ eV \Rightarrow e = 1$

③ $K = 20.4\ eV \Rightarrow e = 1,\ e = 0$

④ $K = 22\ eV \Rightarrow e = 1,\ 0 < e < 1,\ e \neq 0$

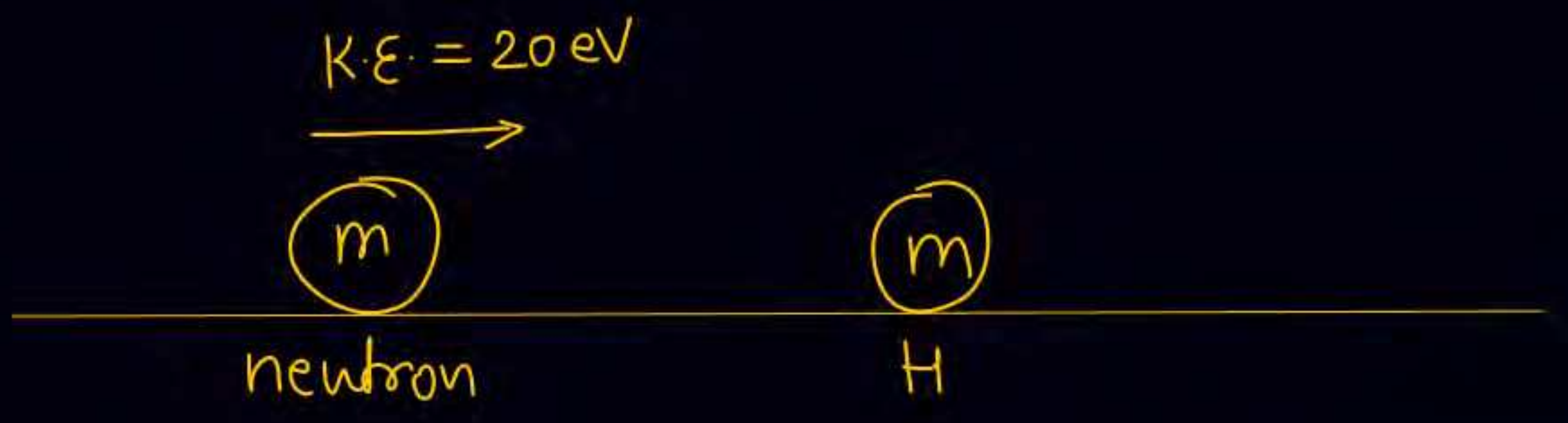
⑤ $K = 24\ eV \quad e = 1,\ 0 < e < 1,\ e \neq 0$

⑥ $K = 24.18\ eV \Rightarrow e = 1,\ 0 < e < 1,\ e = 0$

$\Downarrow$

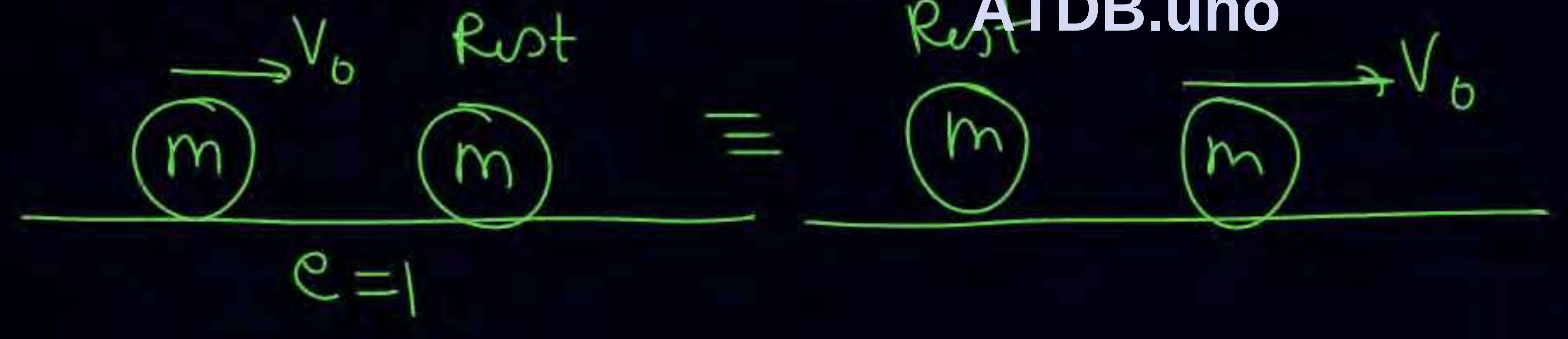
$n = 1 \longrightarrow n = 3$

Q

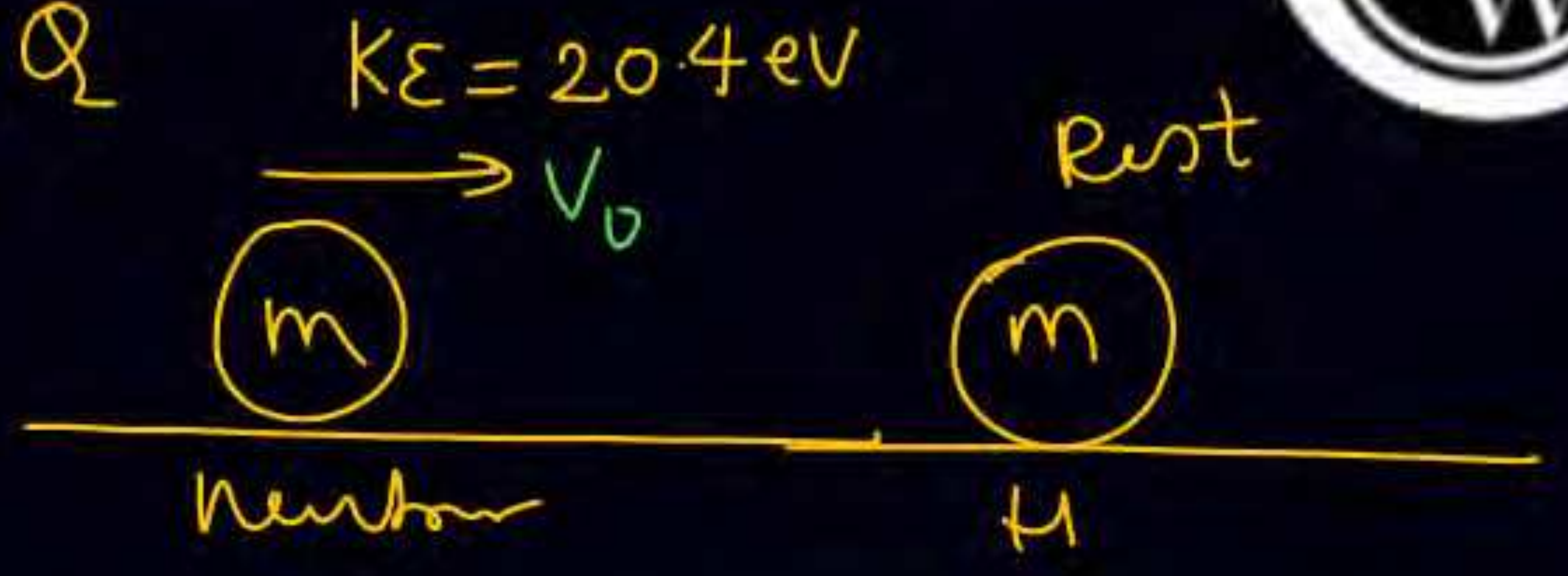


find possible K.E. of H atom after collision

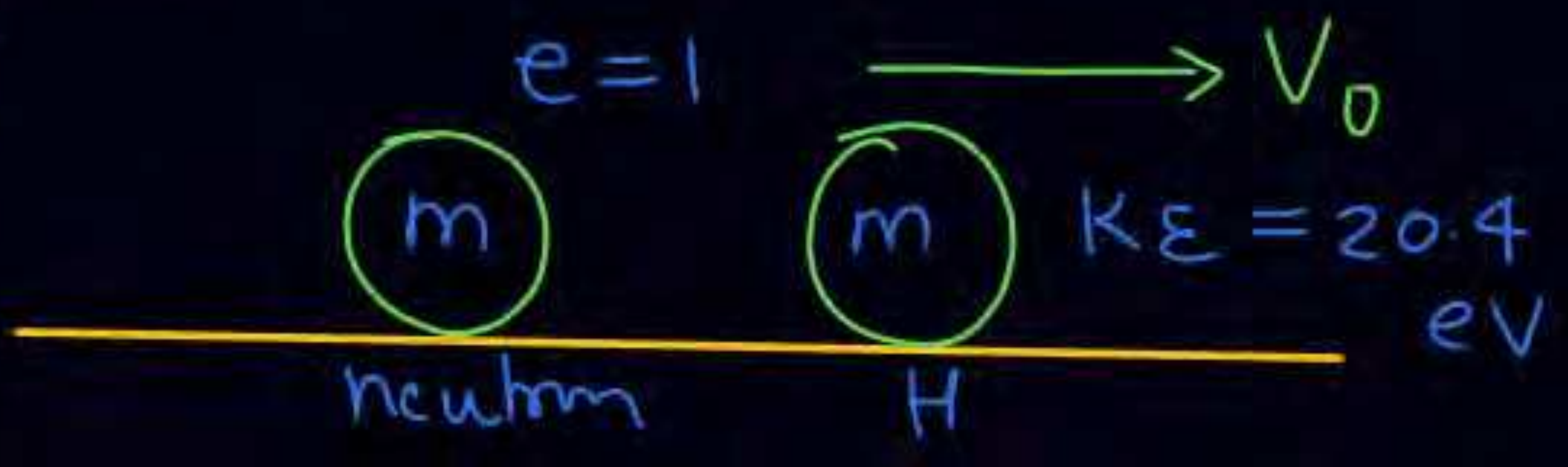
Sol^n $K < 20.4 \Rightarrow e = 1$



Q

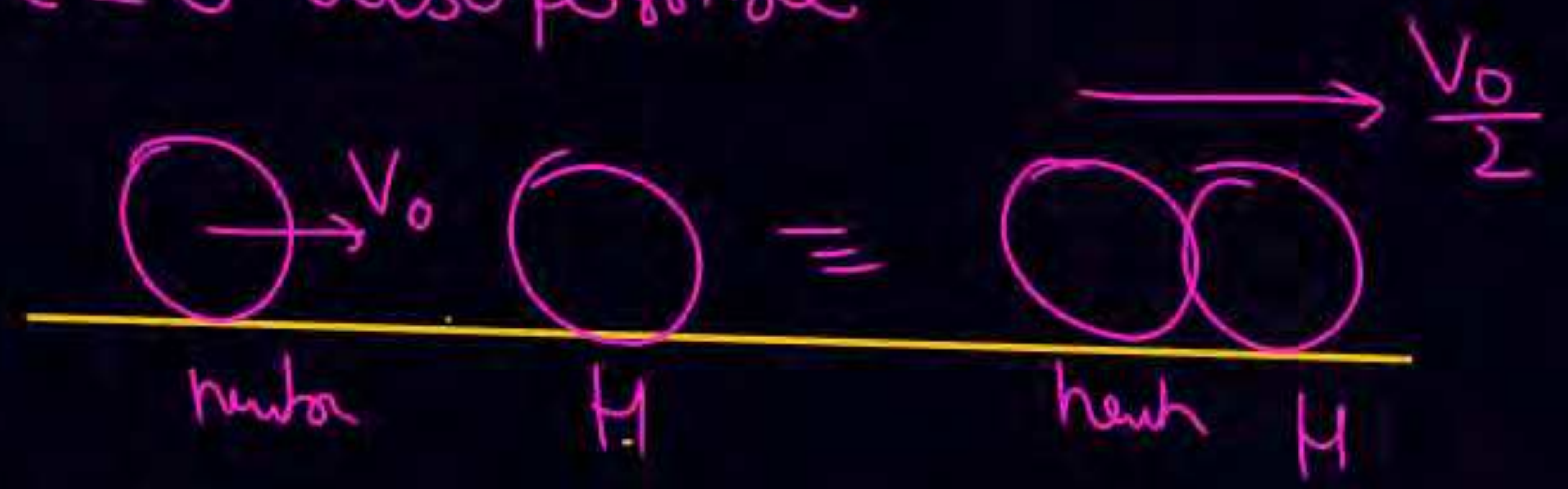


Sol^n



or

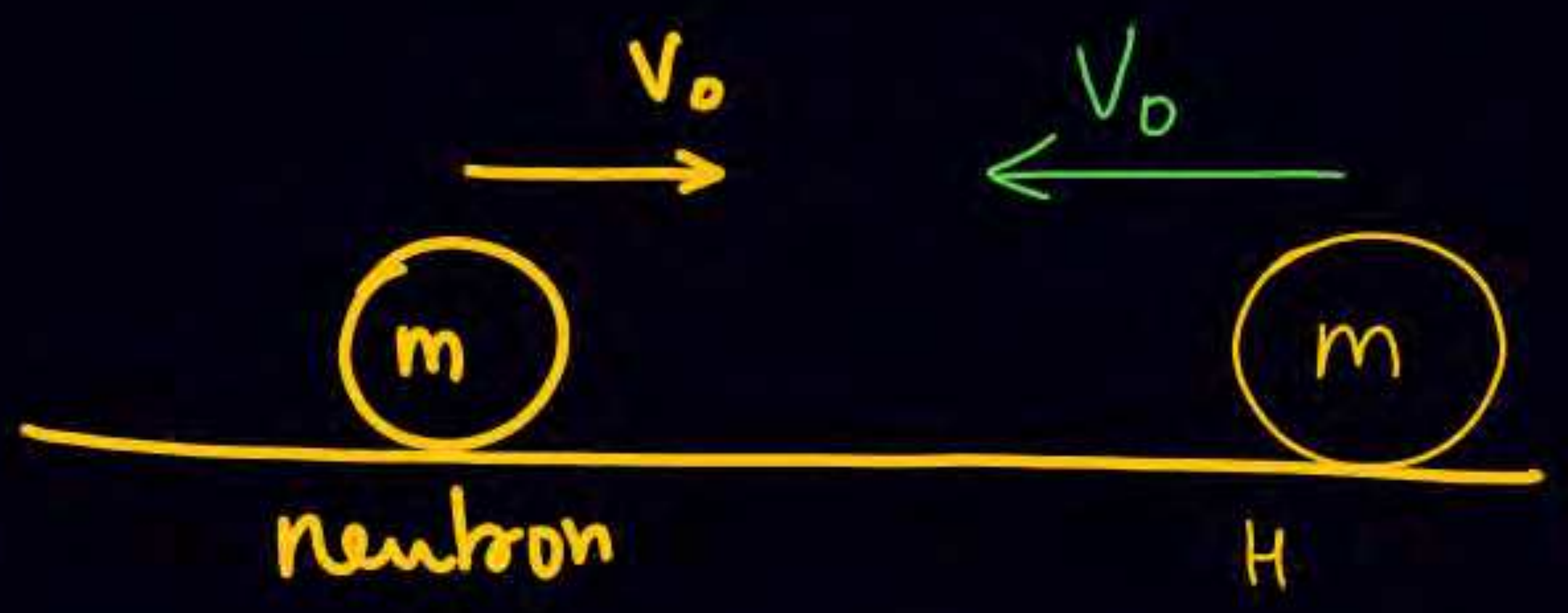
$e = 0$ also possible



$(KE)_{\text{neutron to pass after collision}} = 5.1$

ADV

Q



If KE of both neutron & H is same and 6.4 eV each. find possible KE of neutron or H after collision.

$$(KE)_i = \frac{1}{2}mv_0^2 + \frac{1}{2}mv_0^2 = mv_0^2$$

$$(\Delta KE)_{loss} = \frac{1}{2}\mu u_{rel}^2(1-e^2)$$

$$(max)_{e=0} = \frac{1}{2}\cdot\frac{m}{2}\cdot(2v_0)^2(1-0^2)$$

$$= mv_0^2 = \text{All initial KE.}$$

Sol^n max possible $(KE)_{loss} = 6.4 + 6.4 = 12.8$ eV

Case 1 $e = 1$

Case 2 10.2 eV ⇒ e^- absorbed

$12.8 - 10.2 = 2.6$ eV
→ 1.3 eV neutron के पास
→ 1.3 eV H के पास

$P_i = 0$

$0 < e < 1$

Case 3 $0 < e < 1$

$e^- \Rightarrow 12.09 \equiv$ electron absorbed $n = 1 \longrightarrow n = 3$

$(\text{Total K.E})_{\text{remain}} = 12.8 - 12.09 = .71$

→ $.355$ eV (N)

→ $.355$ eV ≡ (H)

Case 4 $0 < e < 1$

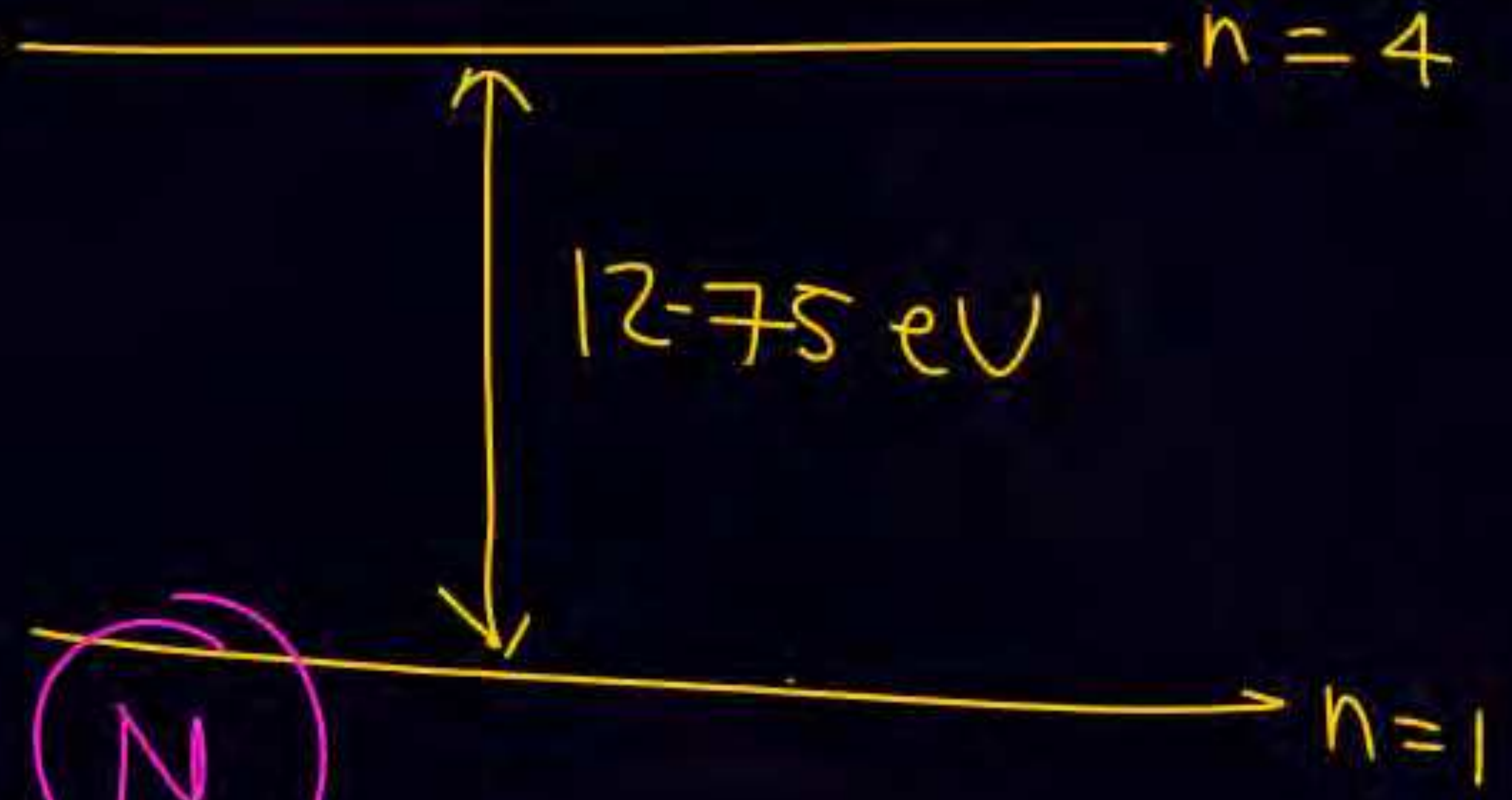
$e^- \equiv 12.75$ eV ≡ e^- absorbed

$n = 1 \longrightarrow n = 4$

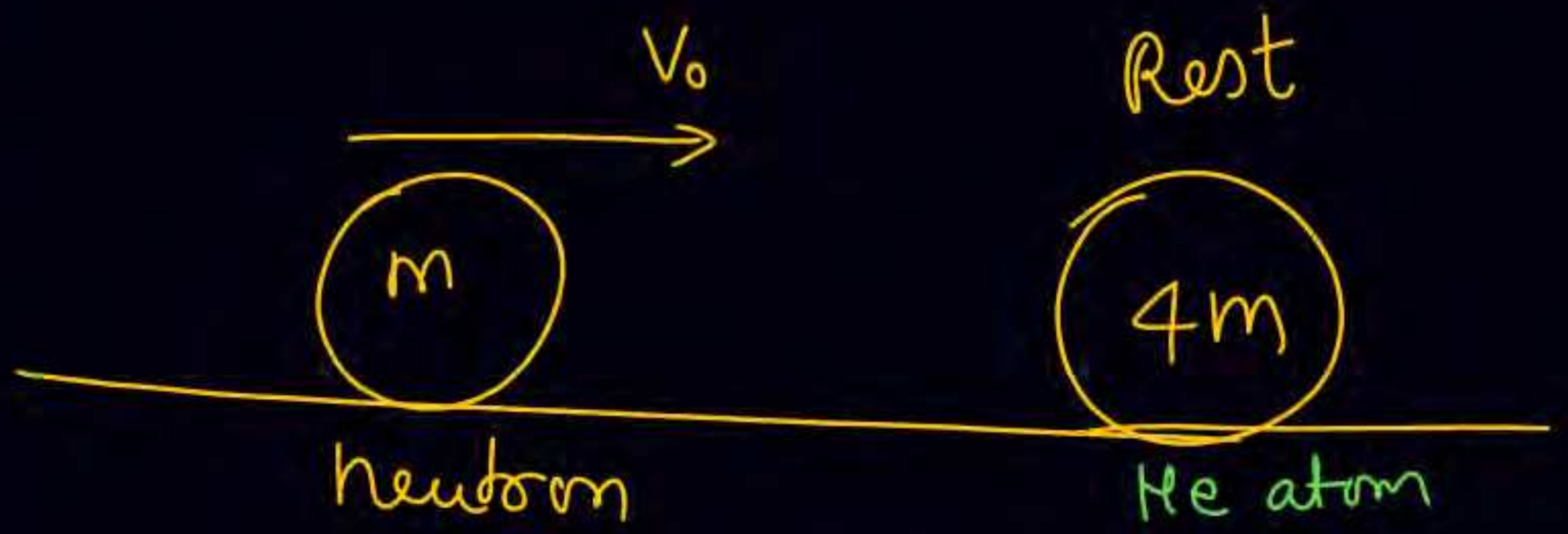
$(\text{Total KE})_{\text{remain}} = 12.8 - 12.75 = .05$ eV

→ $.025$ (N)

→ $.025$ (H)



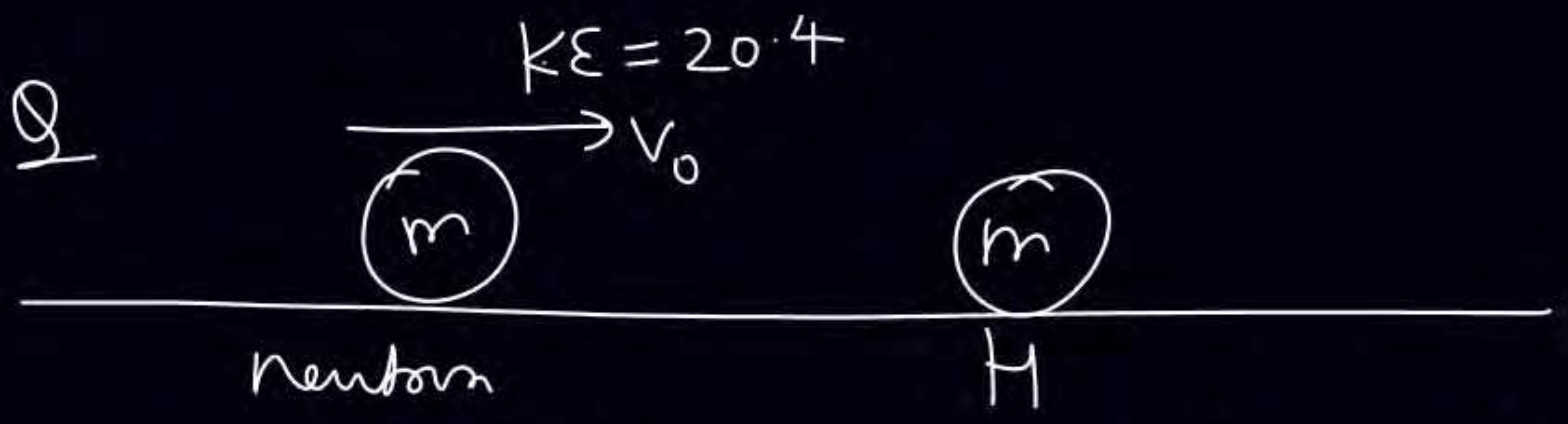
H/W Q



If $K = \frac{1}{2} m V_0^2$

find possible value of K so that all type of collision may occur.

Q



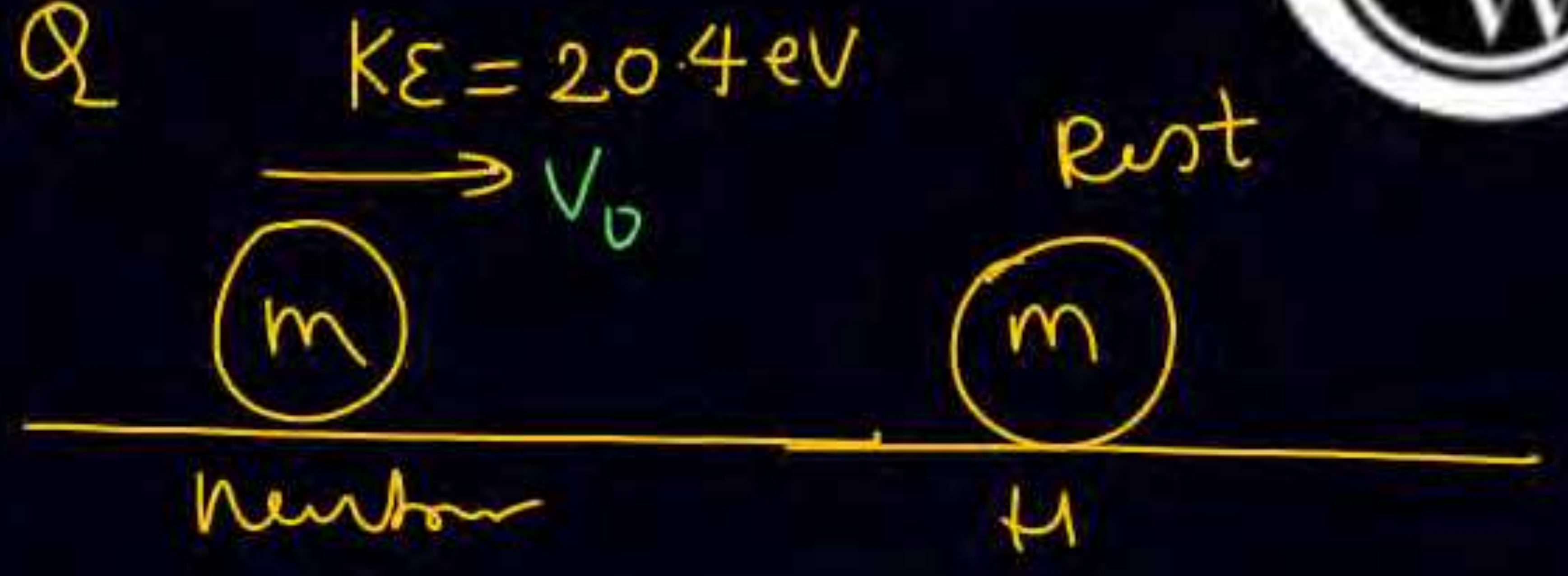
find possible KE of neutron after collision

Sol^n

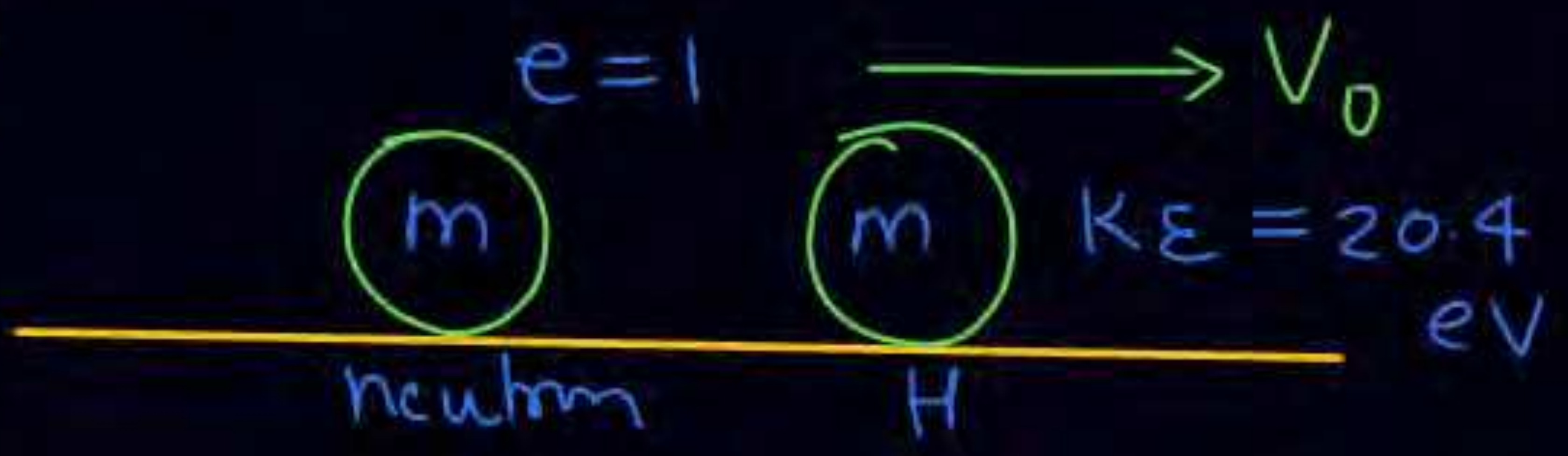
e = 1, KE = 0

e = 0, KE = 5.1

Q

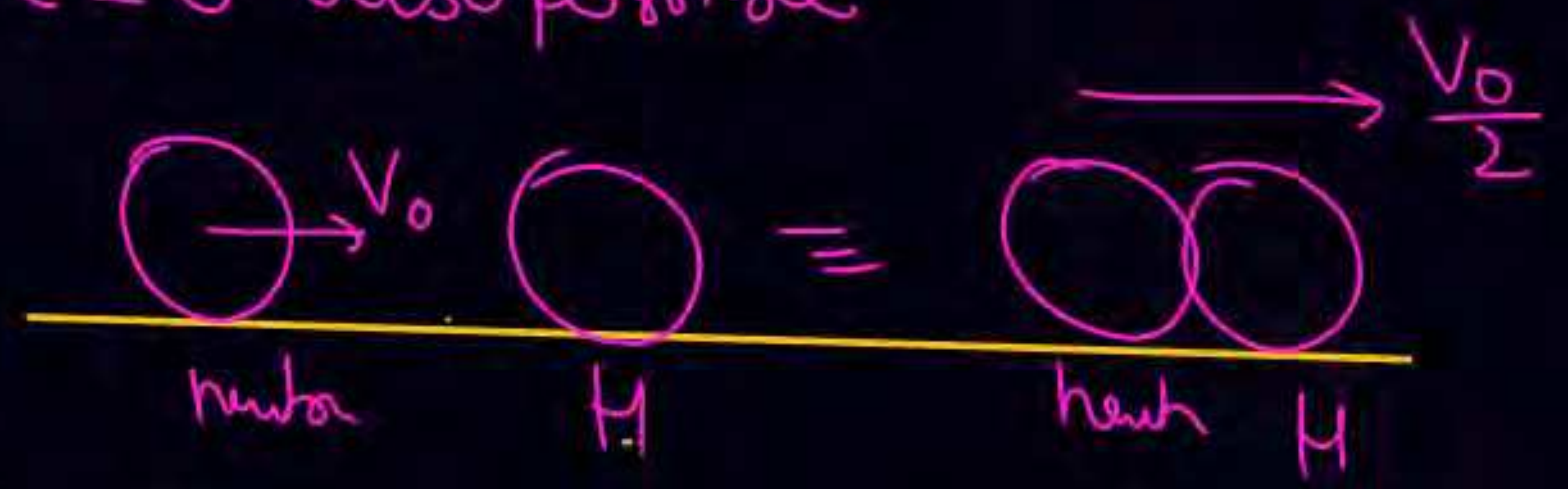


Sol^n



or

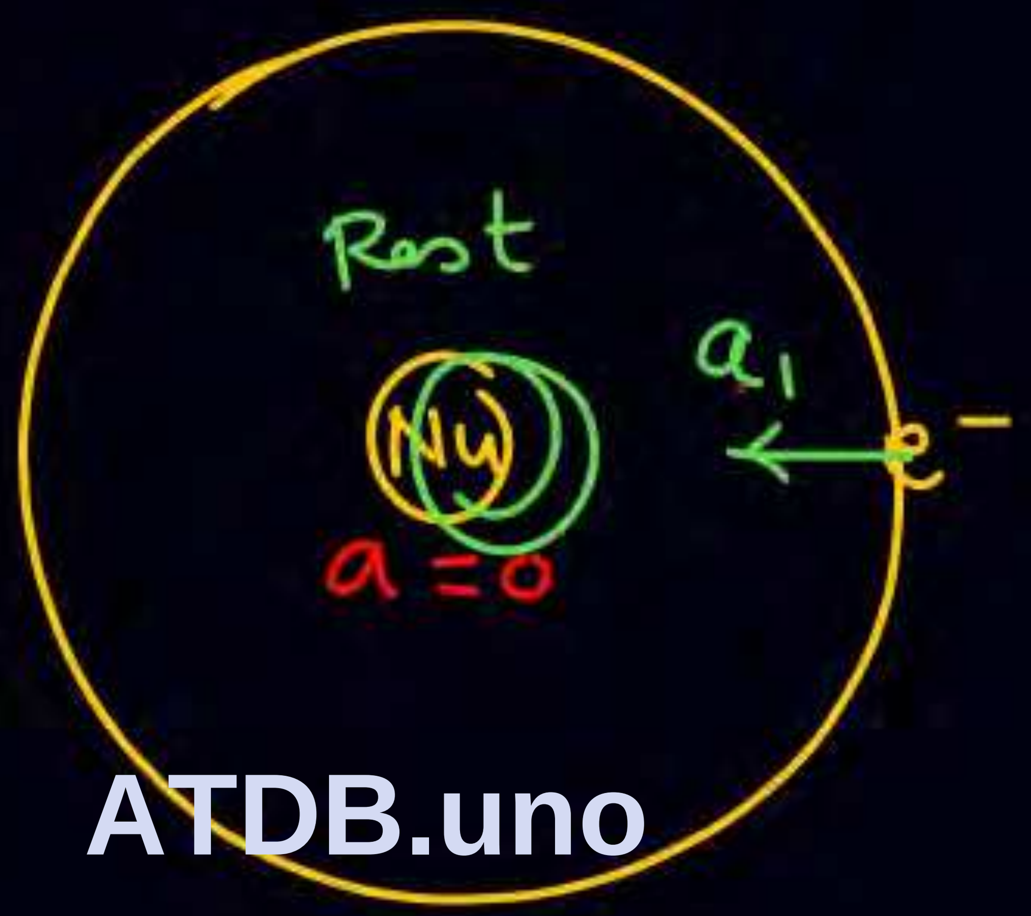
e = 0 also possible



$(KE)_{\text{neutron } \bar{\text{s}} \text{ pass after collision}} = 5.1$

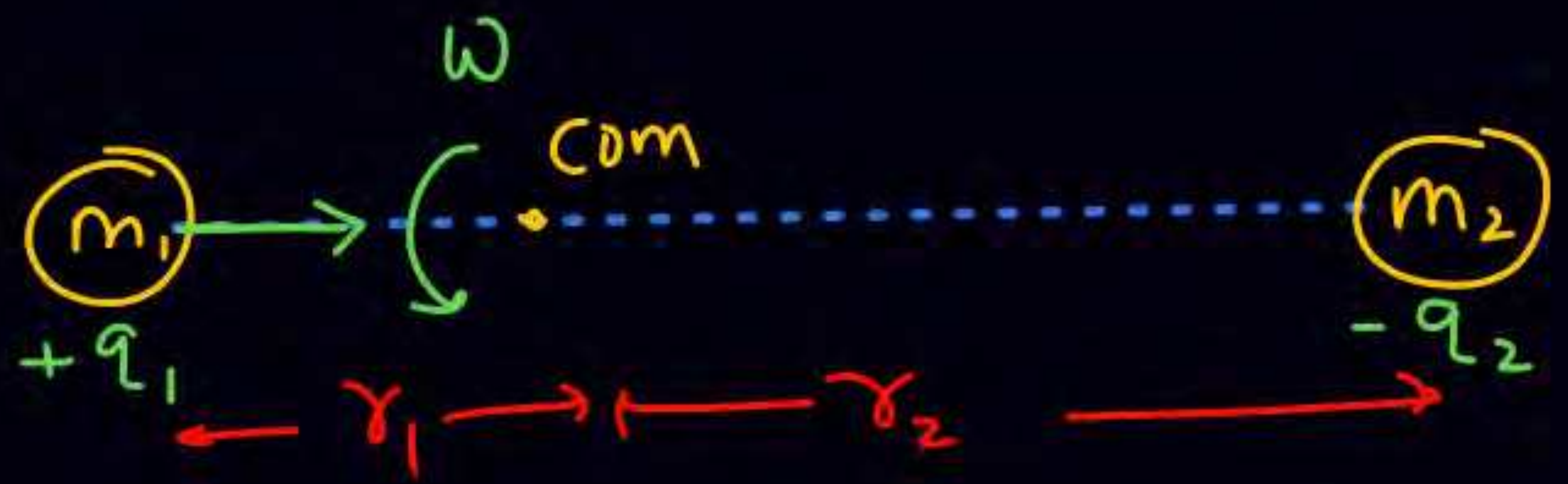
$$F_{net} = 0$$

$$a_{com} = 0$$



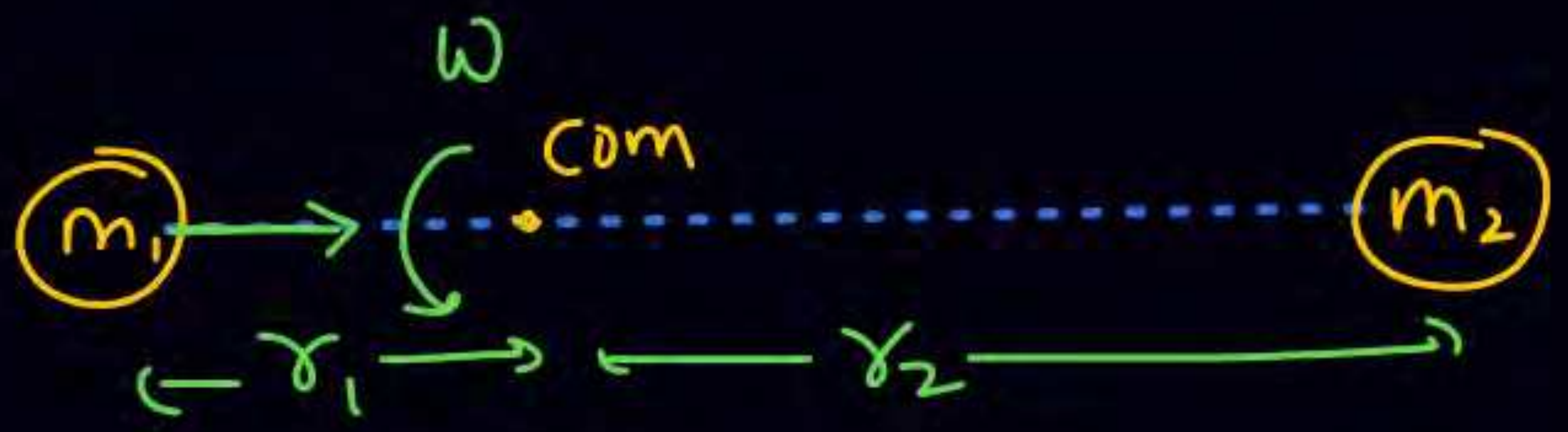
$$a_{com} = \frac{m_1 a_1 + m_2 a_2}{m_1 + m_2} = 0$$

$$m_1 \vec{a_1} + m_2 \vec{a_2} = 0$$



$$F = \frac{kq_1q_2}{r^2} = m_1 r_1 \omega^2$$

$$\frac{kq_1q_2}{r^2} = m_2 r_2 \omega^2$$



$$\frac{G m_1 m_2}{(r_1+r_2)^2} = m_1 r_1 \omega^2$$

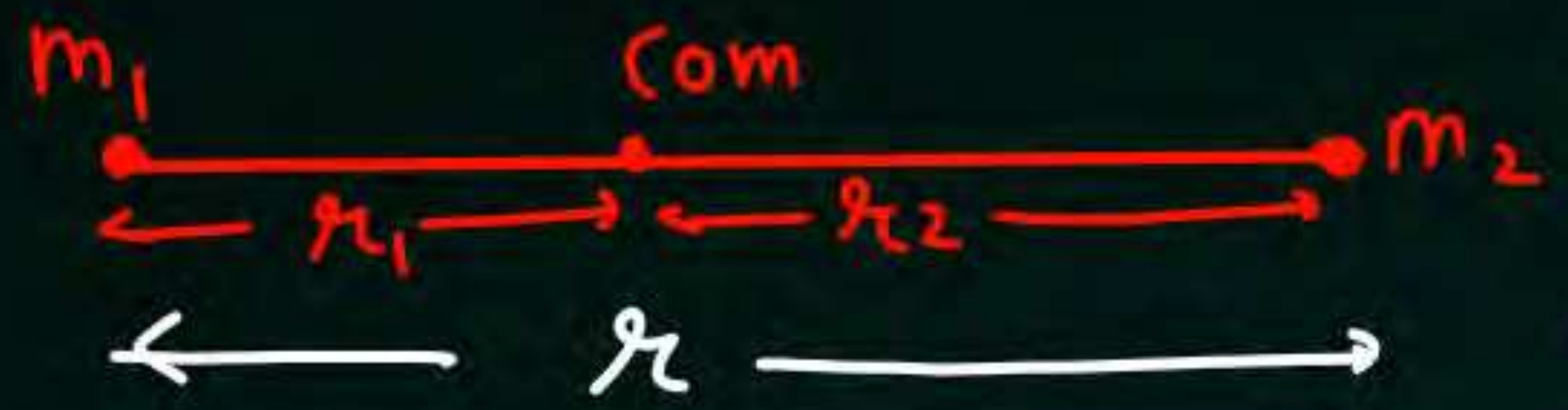
$$= m_2 r_2 \omega^2$$

Effect of nucleus motion

* $$\frac{Kq_1q_2}{r^2} = m_1r_1\omega^2 = m_2r_2\omega^2$$

* $$m_1v_1r_1 + m_2v_2r_2 = \frac{nh}{2\pi}$$

* $$m_1r_1^2\omega + m_2r_2^2\omega = \frac{nh}{2\pi}$$



Solve & get

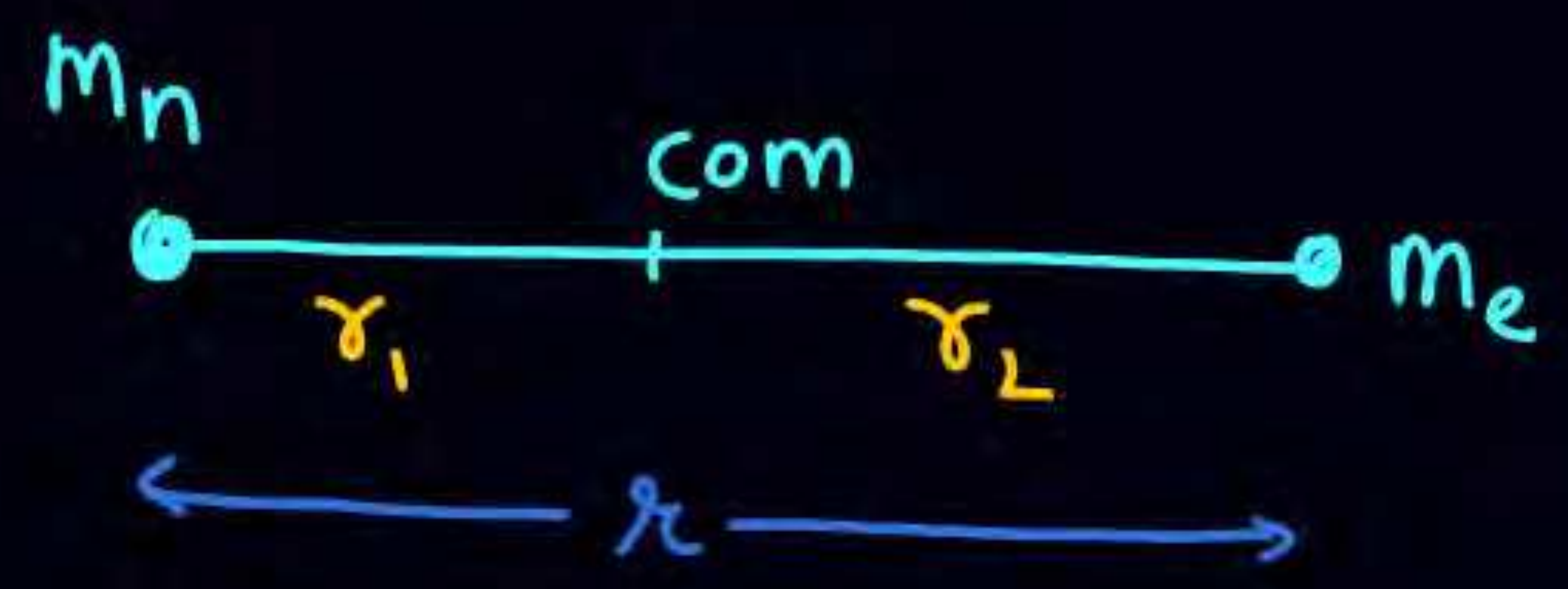
$$r_n = .529\frac{n^2}{Z}\cdot\frac{m_e}{\mu} \rightarrow \text{Å}$$

$$E = -13.6\frac{Z^2}{n^2}\cdot\frac{\mu}{m_e} \rightarrow eV$$

$$\mu = \frac{m_1m_2}{m_1+m_2}$$

(proof math)

$$r_1 = \frac{m_e r}{m_e + m_n} \qquad r_2 = \frac{m_n r}{m_e + m_n}$$



$$m_e r_2 \omega^2 = \frac{kZe^2}{r^2}$$

$$\frac{m_e m_n r}{m_e + m_n}\omega^2 = \frac{kZe^2}{r^2}$$

$$\mu r \omega^2 = \frac{kZe^2}{r^2} \quad \text{—— (1)}$$

$$m_n r_1^2 \omega + m_e r_2^2 \omega = \frac{nh}{2\pi}$$

$$m_n\left(\frac{m_e r}{m_e + m_n}\right)^2 \omega + m_e\left(\frac{m_n r^2}{m_e + m_n}\right)\omega = \frac{nh}{2\pi}$$

$$\frac{m_n m_e}{m_e + m_n} r^2 \omega = \frac{nh}{2\pi}$$

$$\boxed{\mu r^2 \omega = \frac{nh}{2\pi}} \quad \text{—— (2)}$$

Solu — (1) & (2)

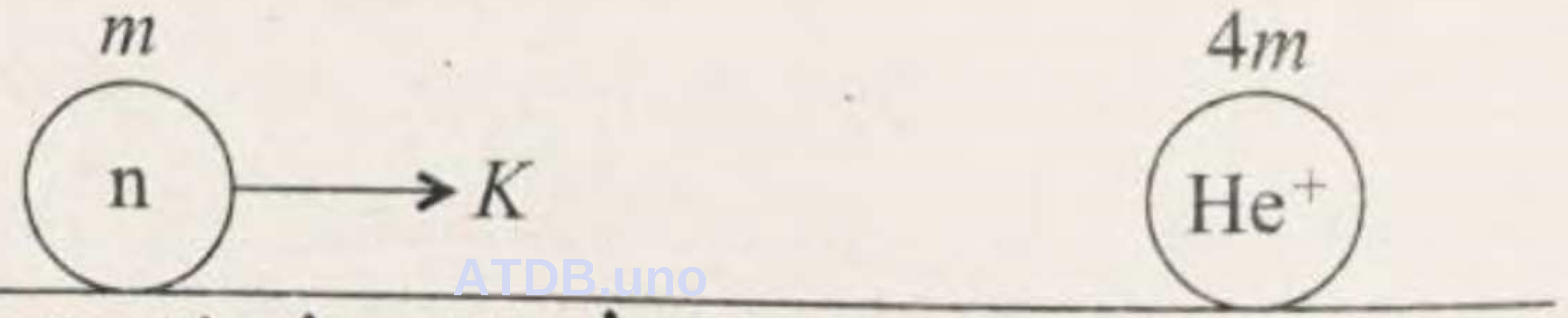
$$\boxed{r_n = \left(.529\,\frac{n^2}{Z}\right)\frac{m_e}{\mu}}$$

In the figure, what type of collision can be possible, if K = 14 eV, 20.4 eV, 22 eV, 24.18 eV (elastic/inelastic/perfectly inelastic).

$K = 14 \Rightarrow e = 1$
$K = 20.4 \Rightarrow e = 1, e = 0$
$K = 22 \Rightarrow e = 1, 0 < e < 1$
$K = 24.18 \Rightarrow e = 1, e = 0, 0 < e < 1$

Head on collision

A He^+ ion is at rest and is in ground state. A neutron with initial kinetic energy K collides head on with the He^+ ion. Find minimum value of K so that there can be an inelastic collision between these two particles.



(b) Kmin so that all type of collision are possible


THANK
YOU
ATDB.uno