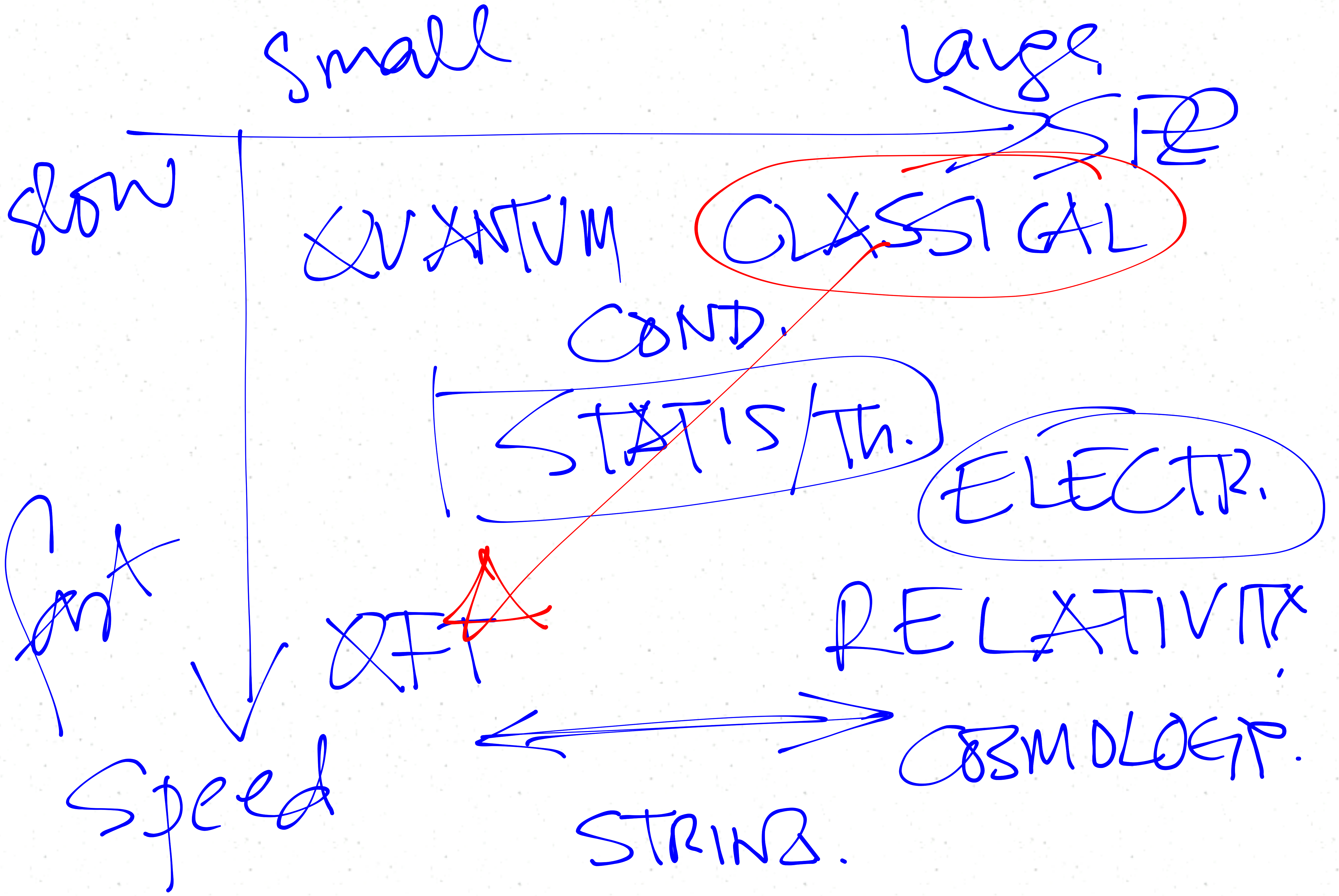
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RELATIVITY.
COSMOLOGY.
STRING.

CLASSICAL

N $\longrightarrow$ Virtual work

D'Alembert $\longrightarrow$ EL

Least Action $\longrightarrow$ EL

$\downarrow$

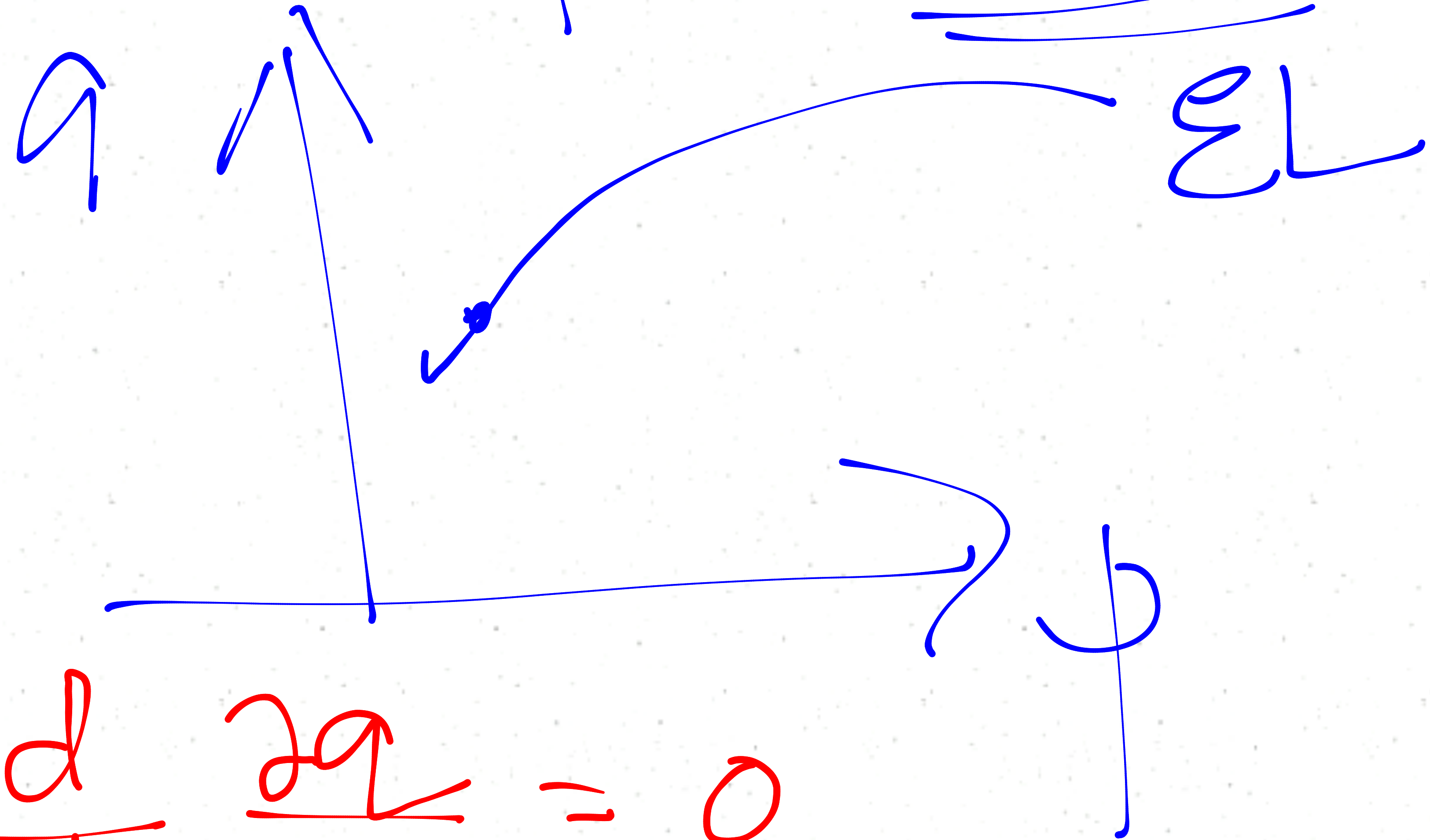
N

$\downarrow$

Hamiltonian formalism

config space $\{q\}$ no $\dot{q}$

phase space $\underline{(p, q)}$



$$\frac{d}{dt}\frac{\partial q}{\partial q} = 0$$

$q, \dot{q}$

$$\frac{\partial f}{\partial x} = 0$$

$$\frac{\partial \dot{q}}{\partial q} \stackrel{?}{=} 0$$

$$L \equiv L(q, \dot{q}) \longrightarrow p = \frac{\partial L}{\partial \dot{q}}$$

$$\int p \, d\dot{q}$$

$$= \int \frac{\partial L}{\partial \dot{q}} \, d\dot{q}$$

$$= L$$

legendre :

$$H = p\dot{q} - L$$

$$L = a(q)\,\dot q^2 - u(q)$$

$$H = p\dot q - L$$

$$dH = d(p\dot q) - dL$$

$\dot p$

p

$$= \cancel{p\,d\dot q} + \dot q\,dp - \left(\frac{\partial L}{\partial q}dq + \cancel{\frac{\partial L}{\partial \dot q}d\dot q}\right)$$

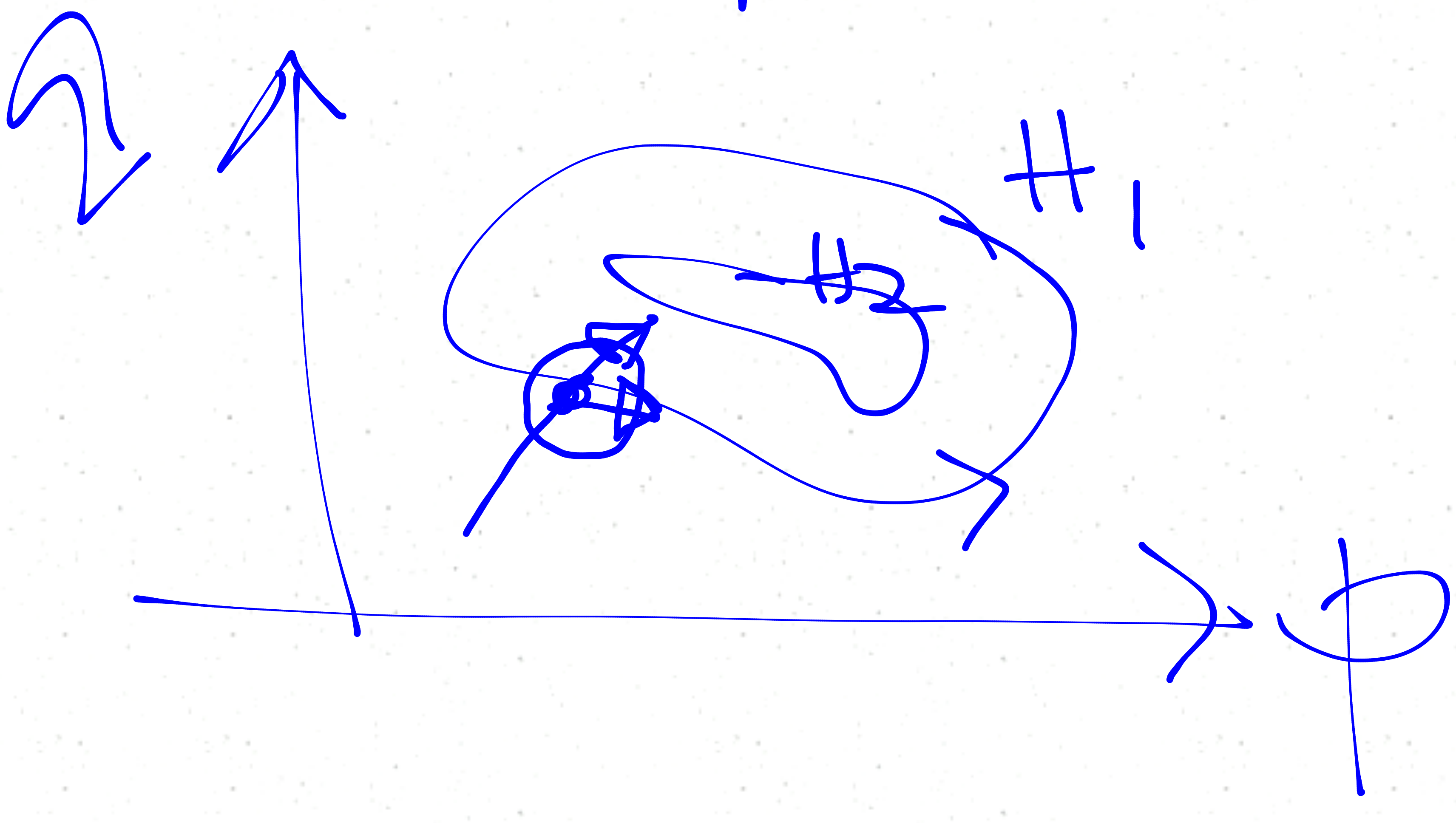
$$dH(p,q) = \dot{q}\,dp - \dot{p}\,dq$$

$$\hookrightarrow = \frac{\partial H}{\partial p}dp + \frac{\partial H}{\partial q}dq$$

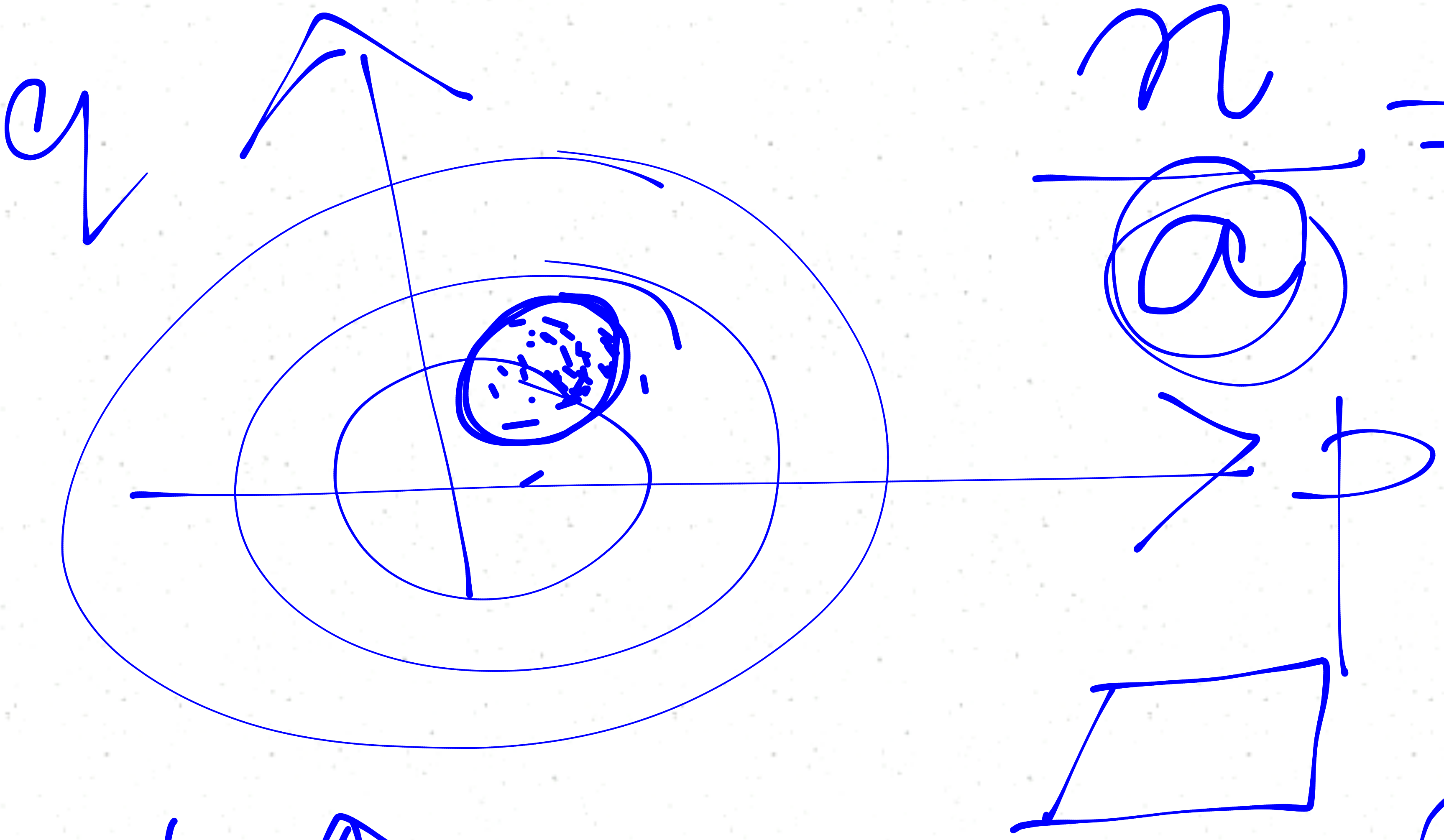
$$\boxed{\begin{aligned} \dot{p} &= -\frac{\partial H}{\partial q} \\ \dot{q} &= \frac{\partial H}{\partial p} \end{aligned}}$$

$$\frac{dH}{dt} = \frac{\partial H}{\partial p}\dot{p} + \frac{\partial H}{\partial q}\dot{q}$$

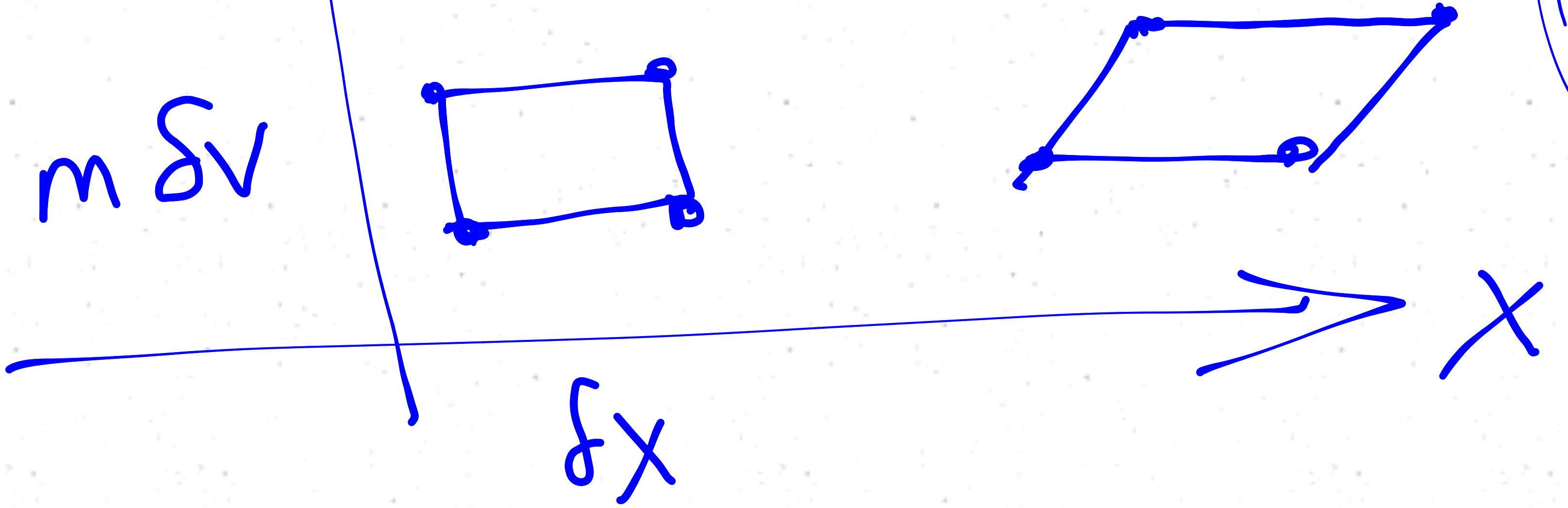
$$= \dot{q}\dot{p} - \dot{p}\dot{q} = 0$$

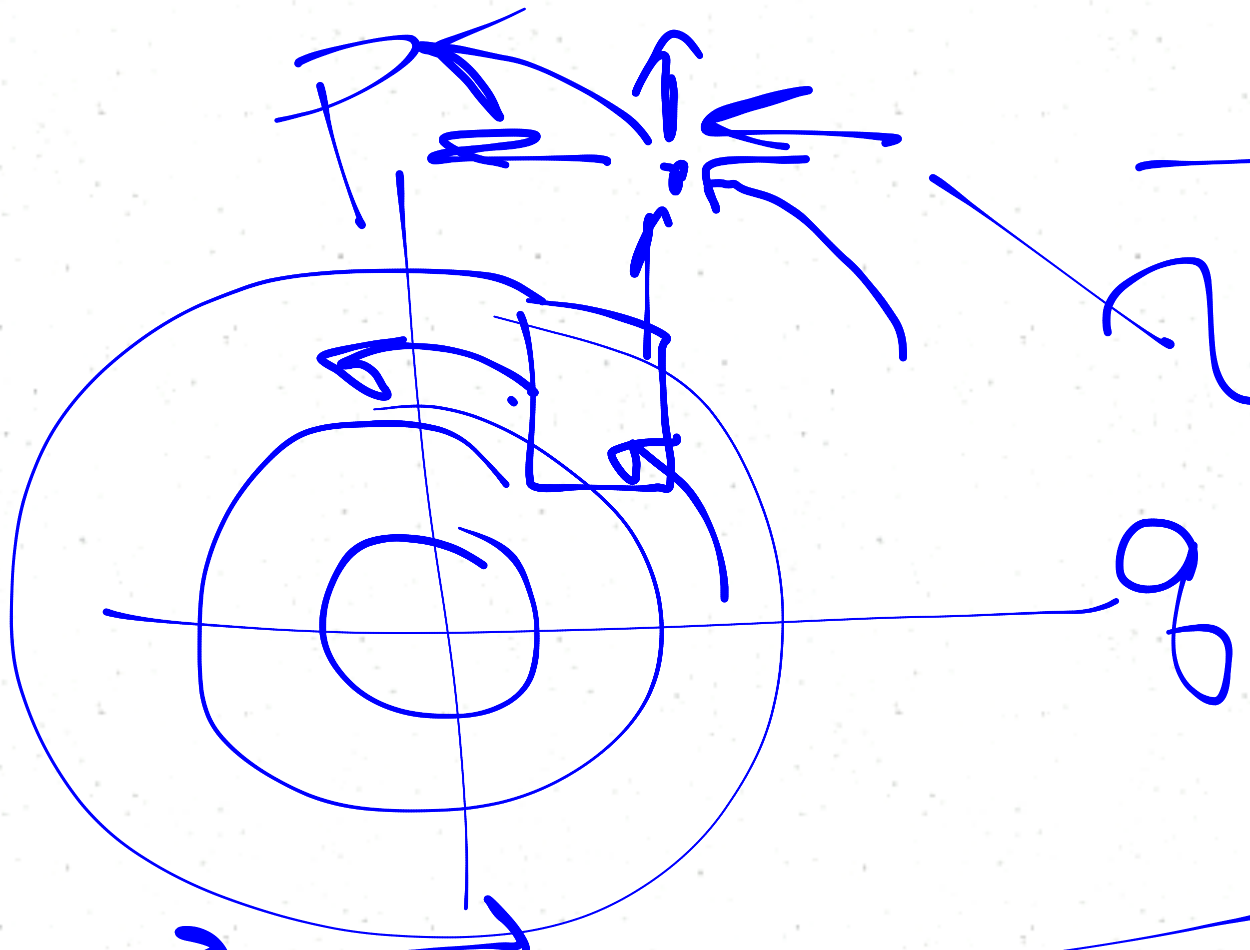


$$\frac{h}{a} = p$$



$$\Delta p \Delta x \geq \hbar$$





$$\vec{v} = \boxed{(\dot{q}, \dot{p})}$$

$$\vec{\nabla} \cdot \vec{v} = \frac{\partial \dot{q}}{\partial q} + \frac{\partial \dot{p}}{\partial p}$$

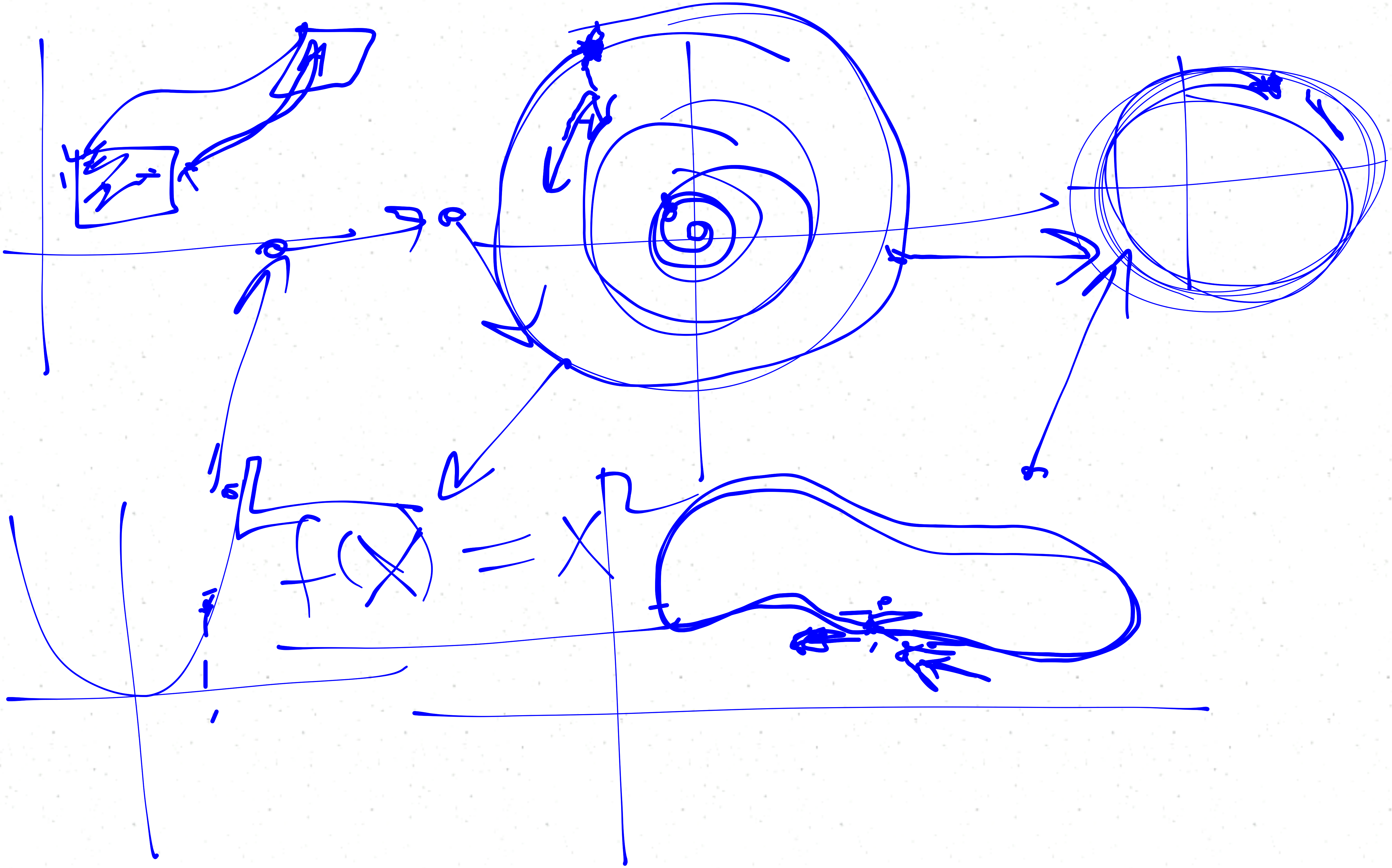
$$= \frac{\partial}{\partial q}\left(\frac{\partial H}{\partial p}\right) - \frac{\partial}{\partial p}\left(\frac{\partial H}{\partial q}\right)$$

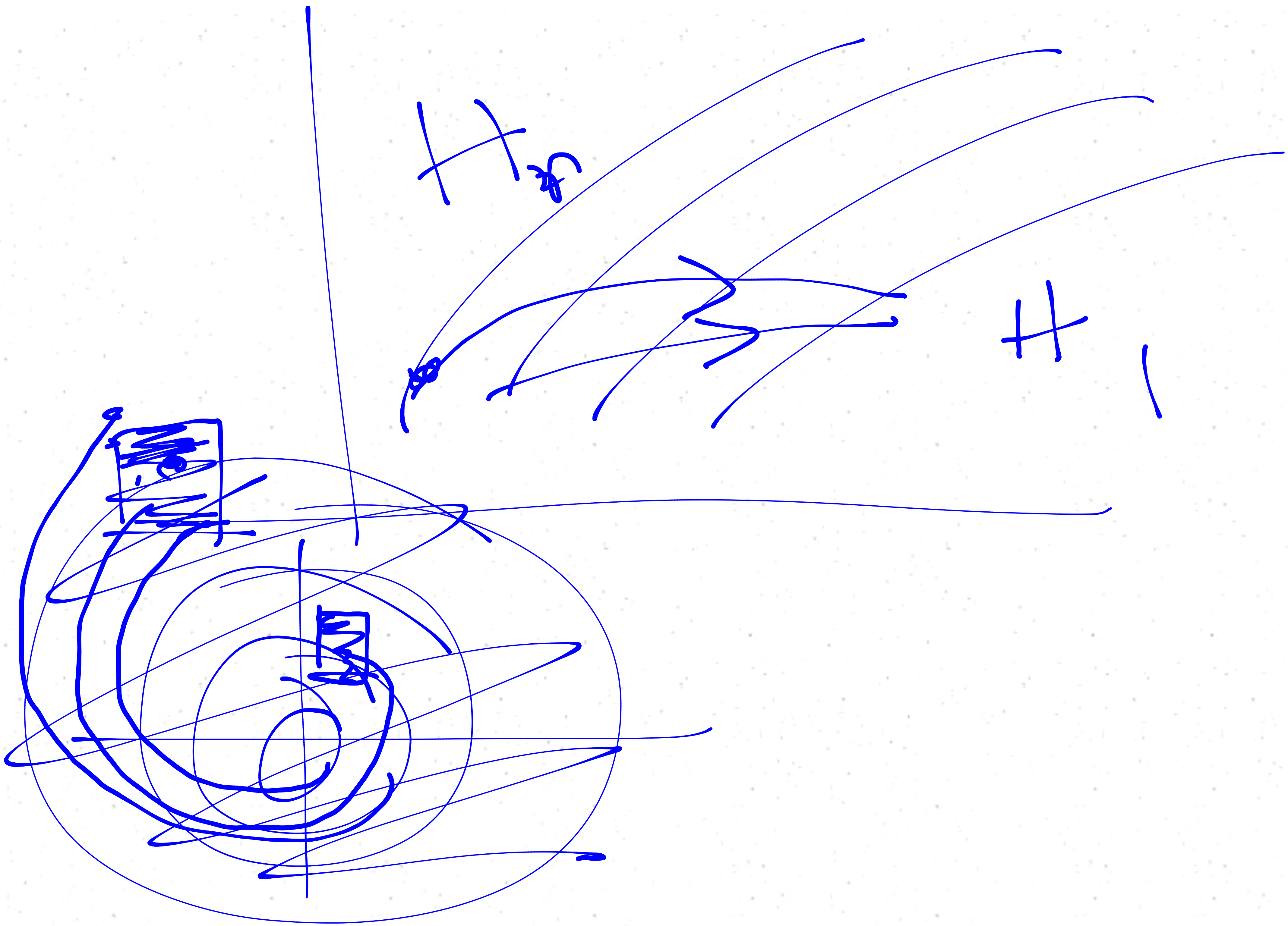
$$= 0$$

$$\vec{v} = \boxed{\dot{p}\,\hat{e}_p + \dot{q}\,\hat{e}_q}$$

$$\vec{\nabla}\cdot\vec{v} = \left(\frac{\partial}{\partial p}\hat{e}_p + \frac{\partial}{\partial q}\hat{e}_q\right)$$

$$+ \;\cdot\; \Big($$


f(x) = x


H
H 1

ROUTH

$$L \equiv L(q_1, \dot{q}_1, q_2, \dot{q}_2)$$

$$H \equiv H(q_1, p_1, q_2, p_2)$$

$\dot{q}_2$

$$H = \sum_{i=1}^{2} \dot{q}_i p_i - L$$

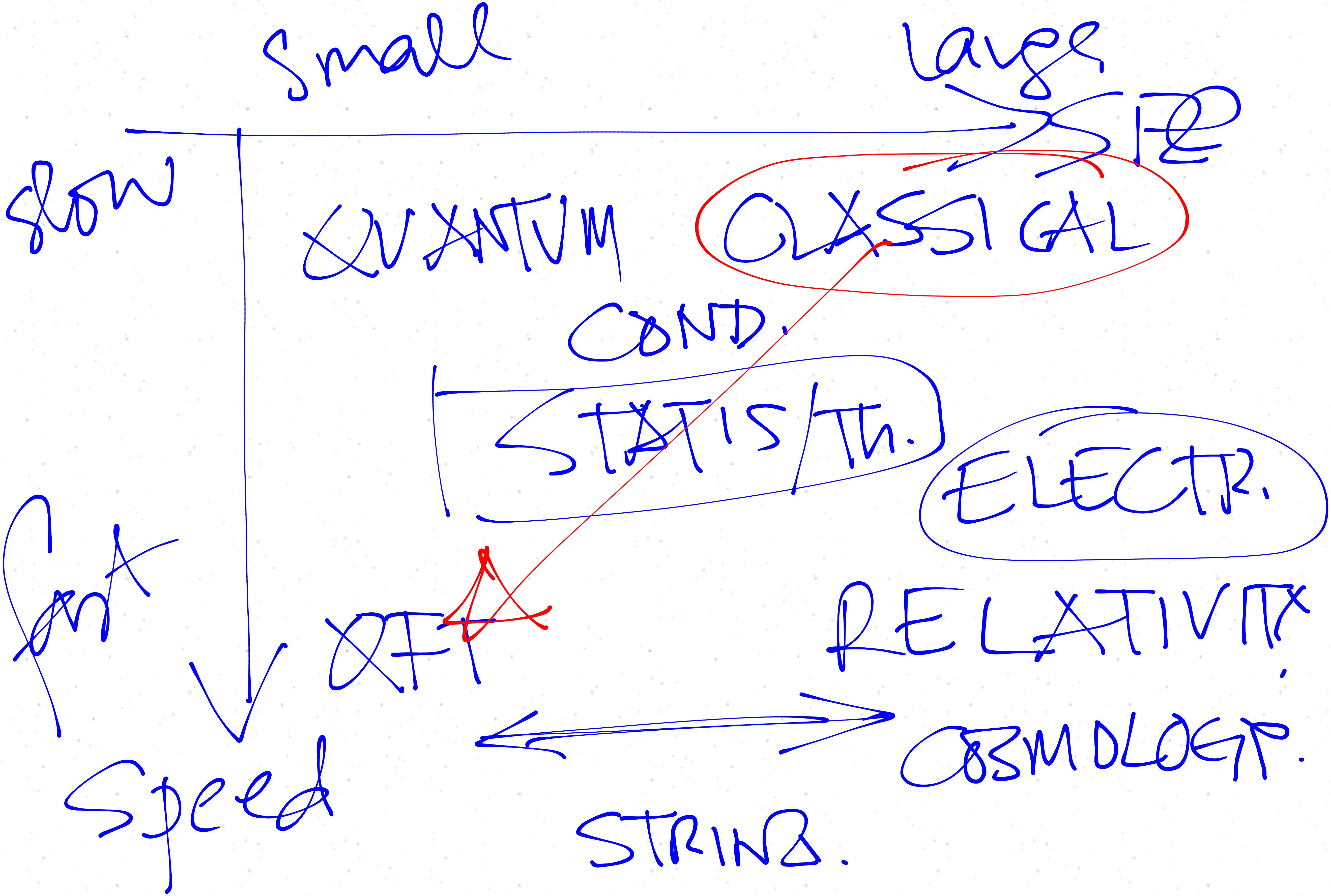
$$R \equiv R(q_1, p_1, q_2, \dot{q}_2)$$

$$H = p_i \dot{q}_i - L$$

$$L \equiv L(\dot{q})$$

$$\dot{p} = \cancel{\frac{\partial L}{\partial q}}^{\,0}$$

$$p = \frac{\partial L}{\partial \dot{q}} = c$$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$\boxed{\text{Hamiltonian formalism}}$

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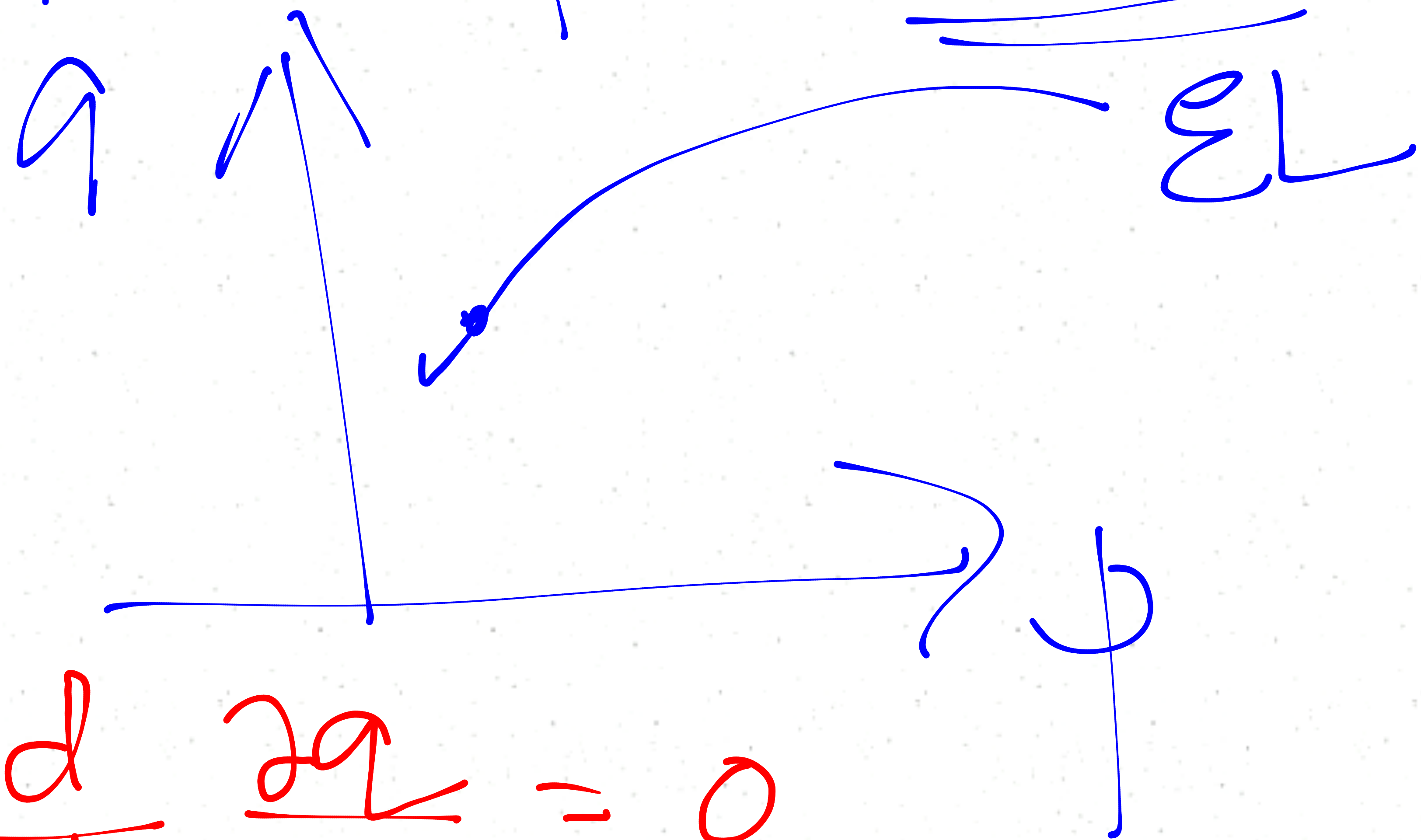
phase space $\underline{(p, q)}$



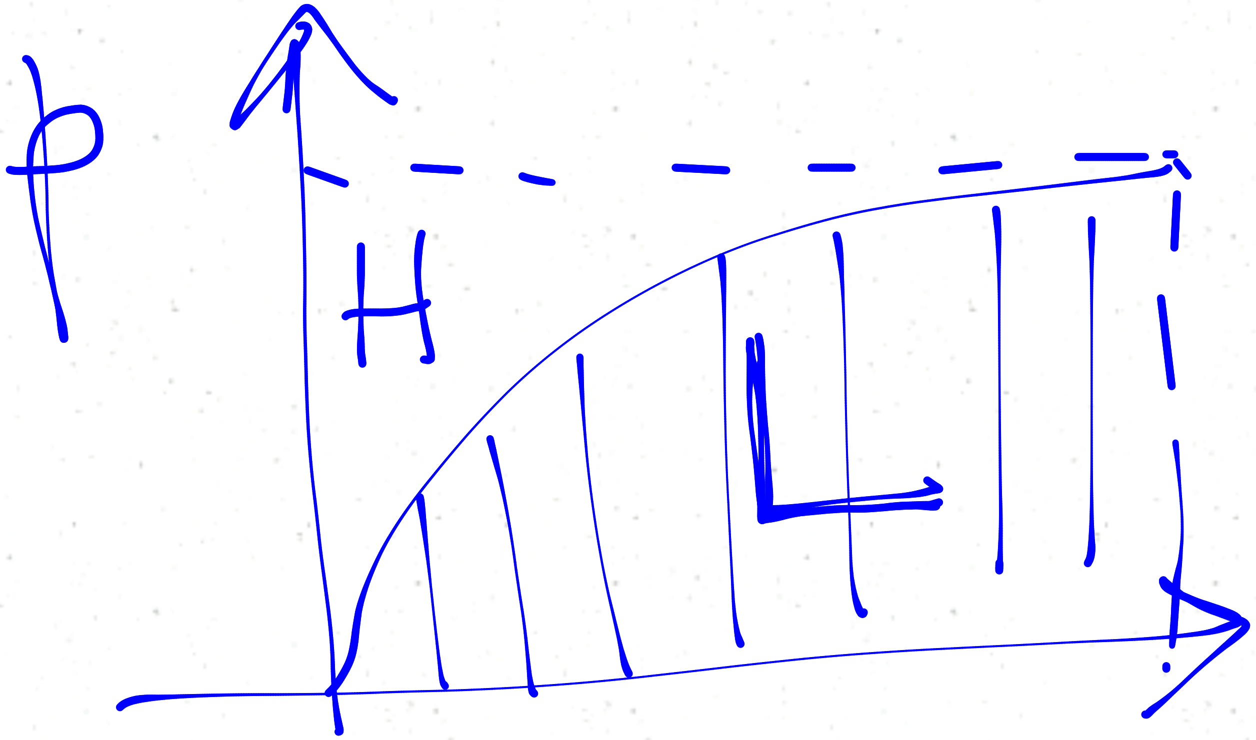
$$\frac{d}{dt}\frac{\partial q}{\partial q} = 0$$

$$q, \dot{q}$$

$$\frac{\partial f}{\partial x} = 0$$

$$\frac{\partial \dot{q}}{\partial q} \overset{?}{=} 0$$

$$L \equiv L(q, \dot{q}) \longrightarrow p = \frac{\partial L}{\partial \dot{q}}$$



$$p(\dot{q}) \qquad \int p \, d\dot{q}$$

$$\dot{q} = \int \frac{\partial L}{\partial \dot{q}} d\dot{q}$$

$$= L$$

legendre :

$$H = p\dot{q} - L$$

$$L = a(q)\dot{q}^2 - U(q)$$

$$H = p\dot{q} - L$$

$$dH = d(p\dot{q}) - dL$$

$$= \cancel{\boxed{p\,d\dot{q}}} + \dot{q}\,dp - \left(\frac{\partial L}{\partial q}dq + \cancel{\boxed{\frac{\partial L}{\partial \dot{q}}d\dot{q}}}\right)$$

$\dot{p}$

p

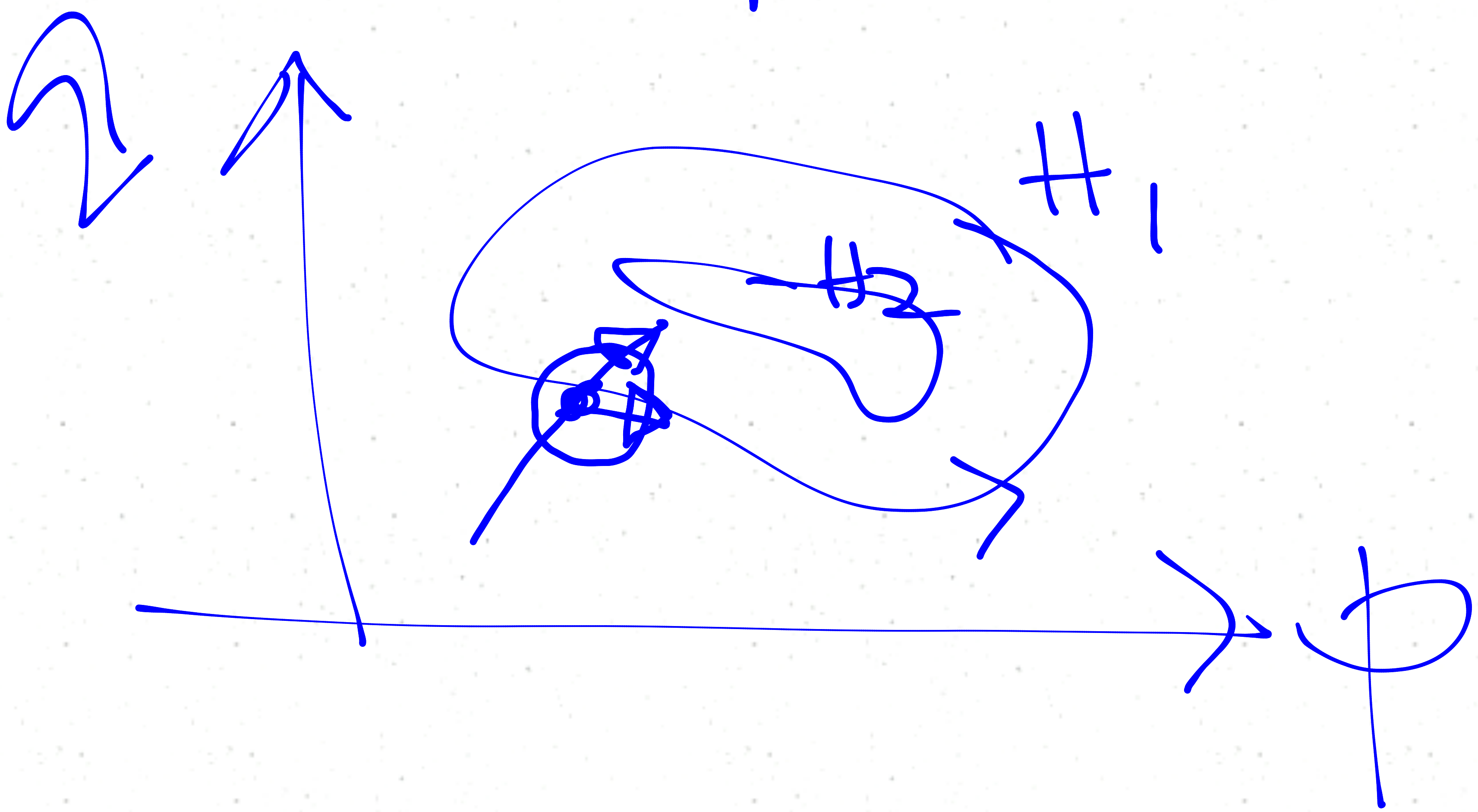
$$dH(p,q) = \dot{q}\,dp - \dot{p}\,dq$$

$$\hookrightarrow = \frac{\partial H}{\partial p}dp + \frac{\partial H}{\partial q}dq$$

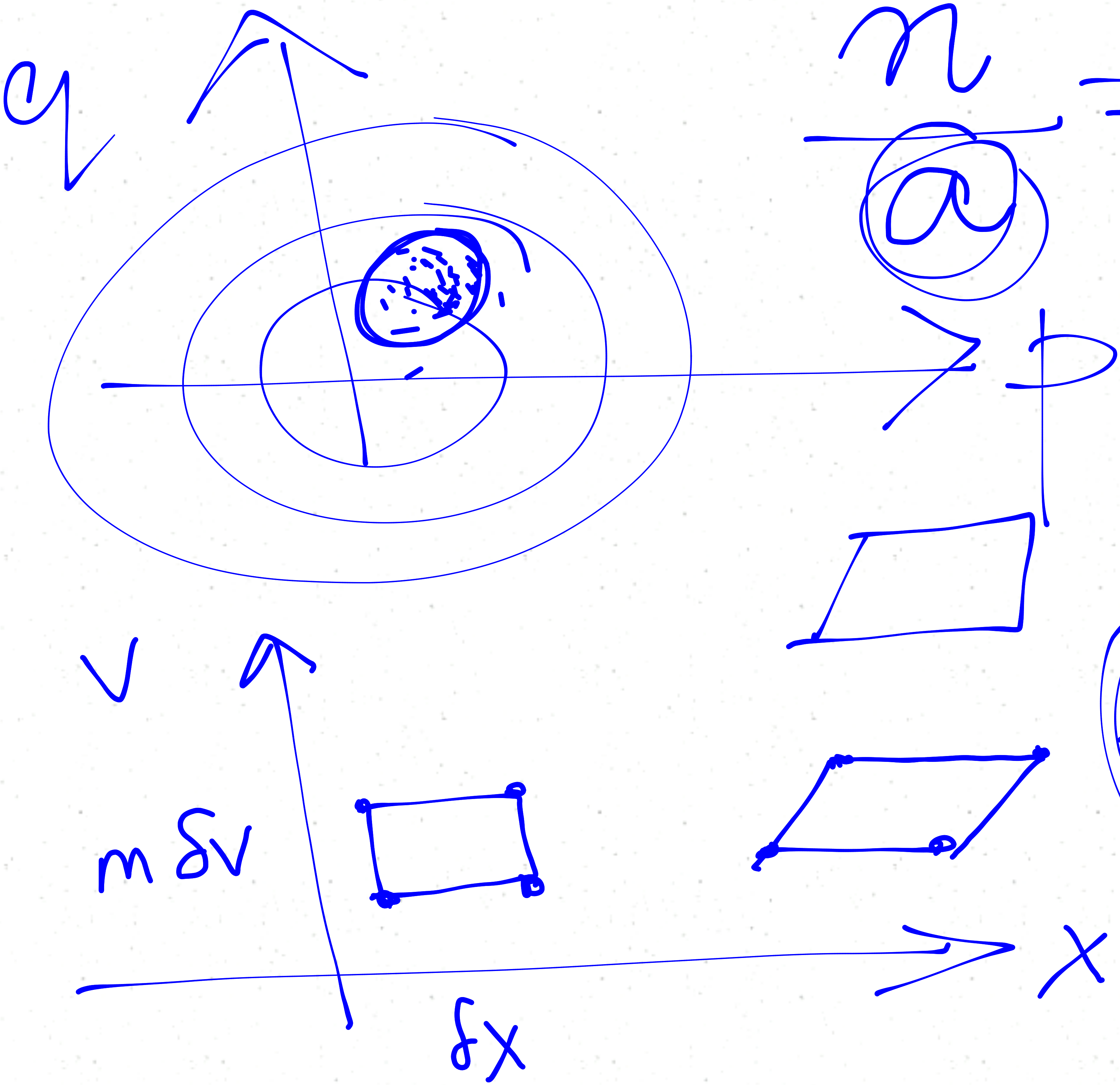
$$\boxed{\begin{aligned} \dot{p} &= -\frac{\partial H}{\partial q} \\ \dot{q} &= \frac{\partial H}{\partial p} \end{aligned}}$$

$$\frac{dH}{dt} = \frac{\partial H}{\partial p}\dot{p} + \frac{\partial H}{\partial q}\dot{q}$$

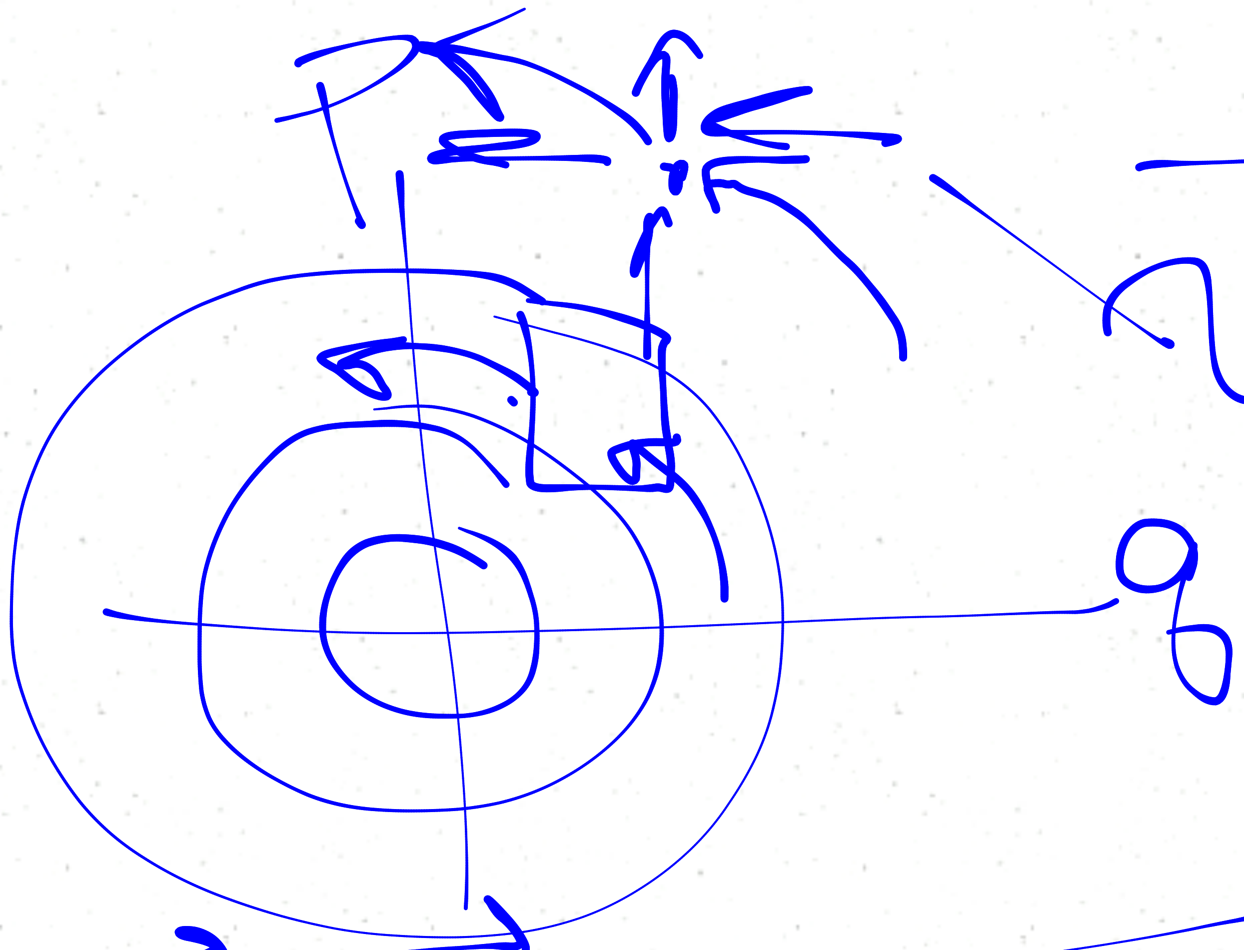
$$= \dot{q}\dot{p} - \dot{p}\dot{q} = \emptyset$$



$$\frac{h}{a} = p$$



$$\Delta p \Delta x \geq \hbar$$



$$\vec{v} = \boxed{(\dot{q}, \dot{p})}$$

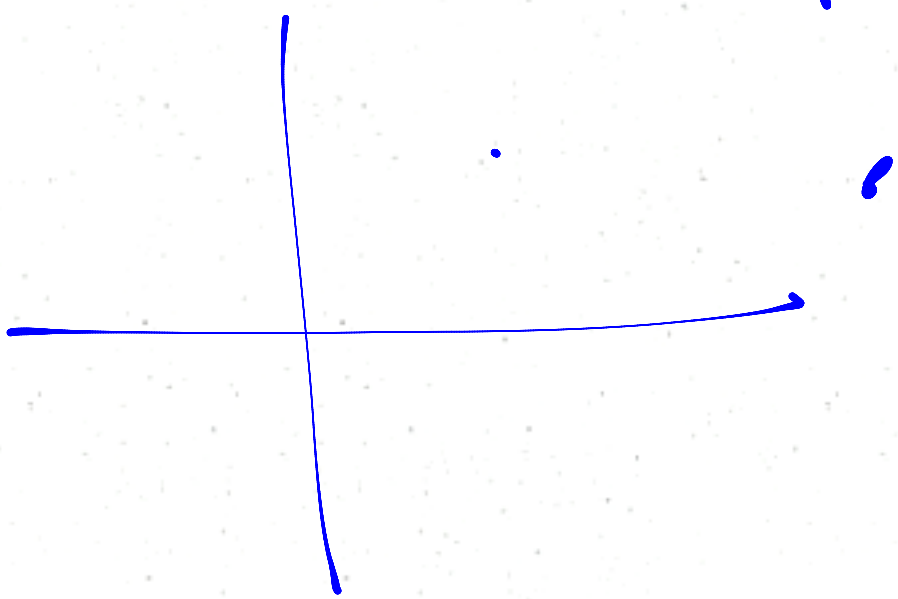
$$\vec{\nabla} \cdot \vec{v} = \frac{\partial \dot{q}}{\partial q} + \frac{\partial \dot{p}}{\partial p}$$

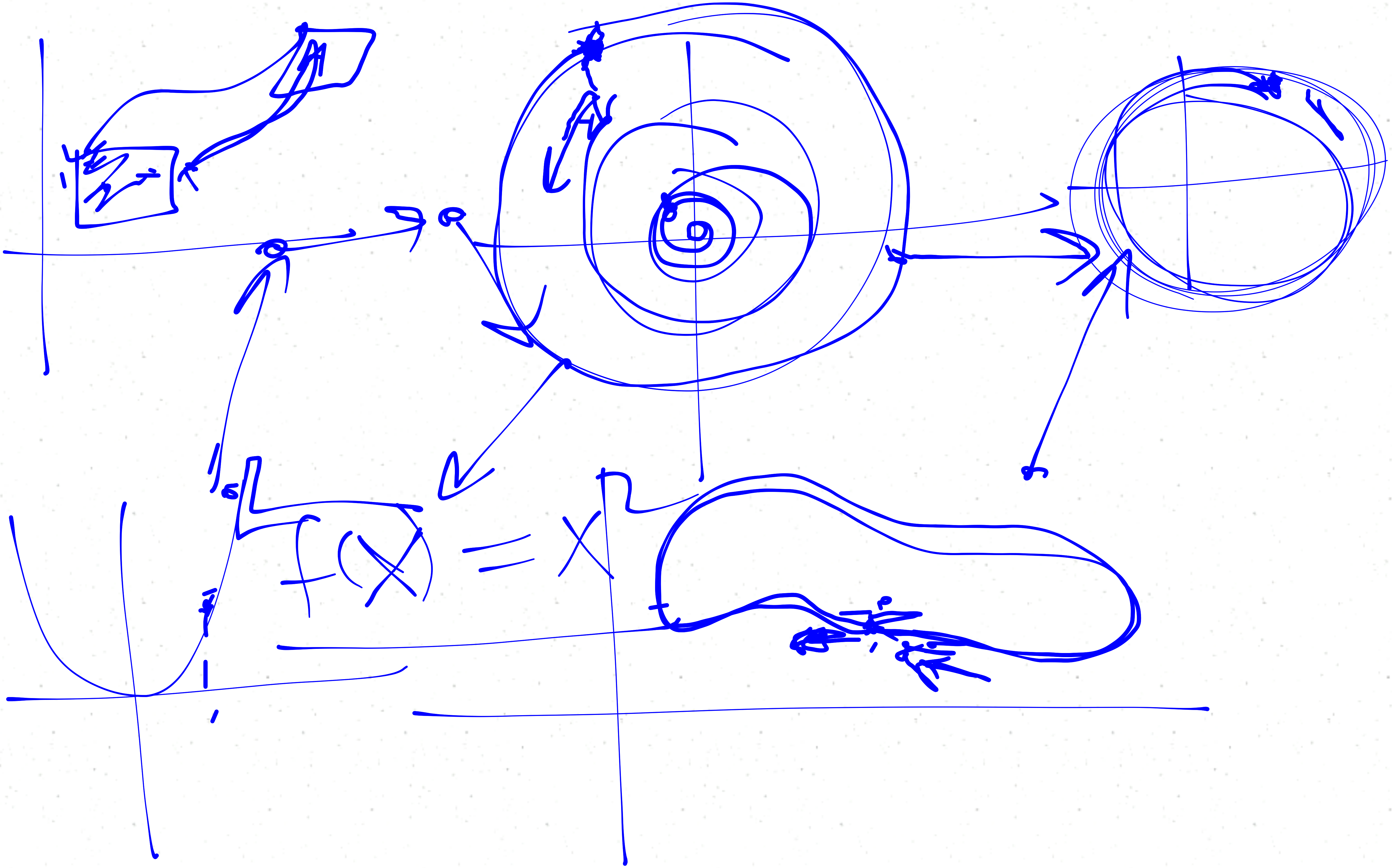
$$= \frac{\partial}{\partial q}\left(\frac{\partial H}{\partial p}\right) - \frac{\partial}{\partial p}\left(\frac{\partial H}{\partial q}\right)$$

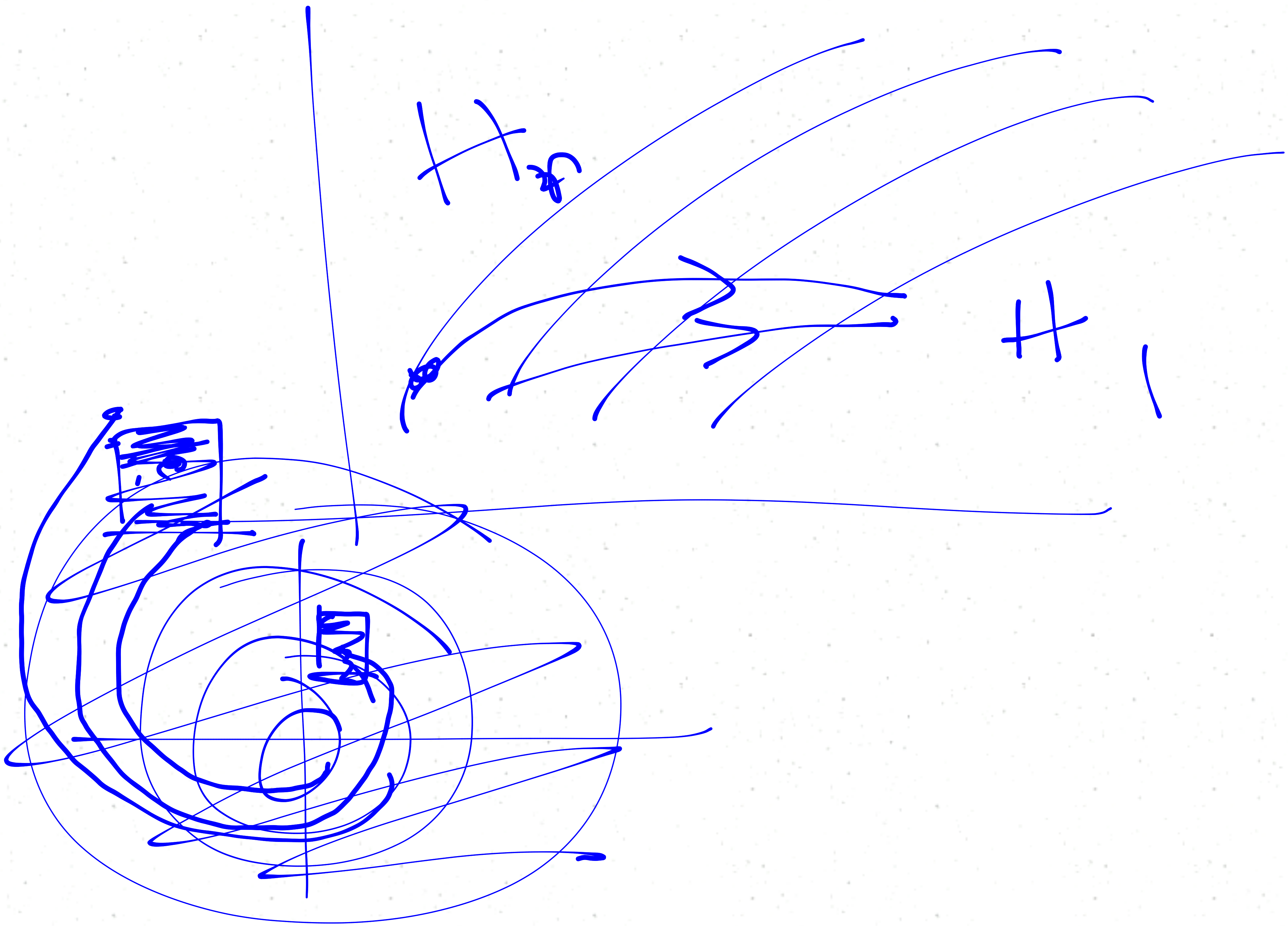
$$= \partial$$

$$\vec{v} = \boxed{\dot{p}\,\hat{e}_p + \dot{q}\,\hat{e}_q}$$

$$\vec{\nabla}\cdot\vec{v} = \left(\frac{\partial}{\partial p}\hat{e}_p + \frac{\partial}{\partial q}\hat{e}_q\right)$$




f(x) = x



ROUTH

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$$H \equiv H(q_1, p_1, q_2, p_2)$$

$\dot{q}_2$

$$H = \sum_{i=1}^{2} \dot{q}_i p_i - L$$

$$R \equiv R(q_1, p_1, q_2, \dot{q}_2)$$

$$R = p_1 \dot{q}_1 - L$$

$$L = L(\dot{q}) \notin L$$

$$p = \frac{\partial L}{\partial \dot{q}} = c$$

$$\dot{p} = \cancel{\frac{\partial L}{\partial q}}^{\,0}$$