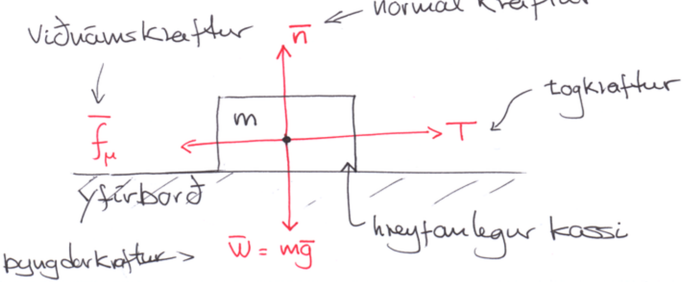
Viðnámskraftar – núningskraftar

Mjög flóknir ⟷ rafkraftar .....

Mjög mikilvægir ⟷ allsstaðar í náttúrunni

↳ Tækni ⟵ hámarka ... / lágmarka

Einfalt líkan



$$\bar{f}_\mu \cdot \bar{n} = 0$$

hornréttir

$$\boxed{f = \mu n}$$

μ_s : viðnámsstuðull

μ_k : hreyfiviðnámsstuðull

2

RAPID COMMUNICATIONS

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Quantum friction and fluctuation theorems

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We use general concepts of statistical mechanics to compute the quantum frictional force on an atom moving at constant velocity above a planar surface. We derive the zero-temperature frictional force using a nonequilibrium fluctuation-dissipation relation, and we show that in the large-time, steady-state regime, quantum friction scales as the cubic power of the atom's velocity. We also discuss how approaches based on Wigner-Weisskopf and quantum regression approximations fail to predict the correct steady-state zero-temperature frictional force, mainly due to the low-frequency nature of quantum friction.

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Theory of quantum friction

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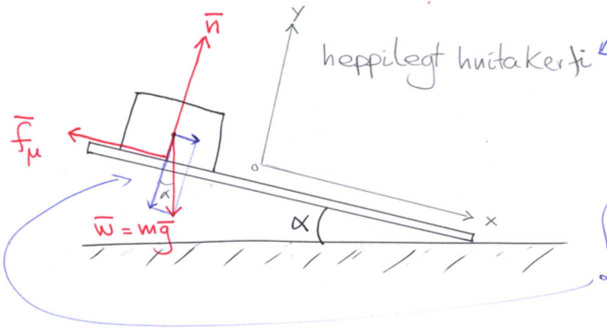
Abstract

Here, we develop a comprehensive quantum theory for the phenomenon of quantum friction. Based on a theory of macroscopic quantum electrodynamics for unstable systems, we calculate the quantum expectation of the friction force at zero temperature, and link the friction effect to the emergence of system instabilities related to the Cherenkov effect. These instabilities may occur due to the hybridization of particular guided modes supported by the individual moving bodies, and selection rules for the interacting modes are derived. It is proven that the quantum friction effect can take place even when the interacting bodies are lossless and made of nondispersive dielectrics.

Erfitt og spennandi
viðfangsefni
ekki gamaldags
eðlisfræði

Dæmi

Kassi kyrr á skábretti, fyrir hvaða horn fer hann af stað?



valið með ás samhliða hreyfingu og öðrum þvert á hana, samsíða normalkrafti

Þyngdarkrafturinn getur haft þátt samsíða báðum ásum

Í y-stefnu

$$n - mg\cos\alpha = 0$$

Í x-stefnu

$$mg\sin\alpha - f_\mu = 0$$

eða

$$\left.\begin{aligned} n &= mg\cos\alpha \\ f_\mu &= mg\sin\alpha \end{aligned}\right\} \rightarrow \underbrace{\frac{f_\mu}{n} = \frac{\sin\alpha}{\cos\alpha} = \tan\alpha}$$

Einfalda líkanið var $f_\mu = \mu_s n$ $\rightarrow$ $\mu_s = \tan\alpha$

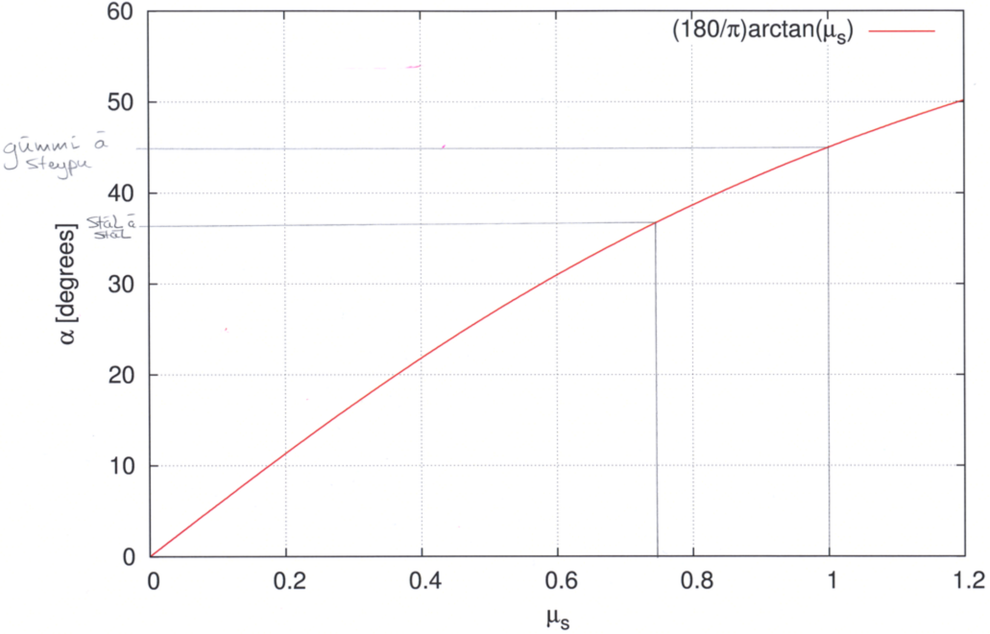
$$\alpha = \arctan(\mu_s)$$

Úr töflu 5.1 í bók:

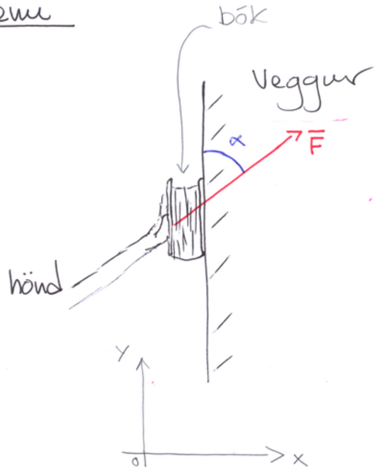
stál á stál $\mu_s = 0{,}74$

teflon á stál $\mu_s = 0.04$

gúmmí á steypu $\mu_s = 1{,}0$ þurrt

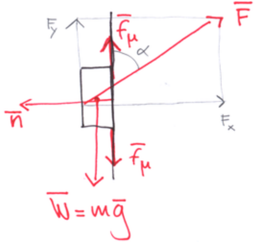

(180/π)arctan(μs)
gúmmí á steypu
stál á stál
α [degrees]
μs
0
10
20
30
40
50
60
0
0.2
0.4
0.6
0.8
1
1.2

Dæmi



Bókinni er haldið kyrri við vegg

a) **Kraftar**



núningskraftur á móti hreyfingu upp eða niður

b) <u>minnsti</u> kraftur til að halda bók kyrri?

α: gefið, svipað og á mynd

→ móti hreyfingu niður

mikill kraftur fyrir hana til að skríða upp vegginn

tilraunir

Engin x-færsla $\rightarrow$ $n = F_x$ lengdir

<u>y-stefna:</u>

$$F_y - mg + f_\mu = 0$$

$$F_y - mg = -f_\mu = -n\mu_s = -F_x \mu_s$$

viðnámskraftur móti hreyfingu niður

$$F\cos\alpha - mg = -F\sin\alpha \cdot \mu_s$$

$$\rightarrow \quad F\left\{\cos\alpha + \mu_s \sin\alpha\right\} = mg$$

$$\rightarrow \quad F = \frac{mg}{\cos\alpha + \mu_s \sin\alpha}$$

lengd F

c) Fyrir hvaða horn α er F minnst í þessari uppsetningu?

$$F(\alpha) = \frac{mg}{\cos\alpha + \mu_s \sin\alpha}$$

finna lágmark $F(\alpha)$, það er þegar

$$\frac{dF(\alpha)}{d\alpha} = 0$$

$$\rightarrow -\frac{\{-\sin\alpha + \mu_s \cos\alpha\}}{\{\cos\alpha + \mu_s \sin\alpha\}^2} = 0$$

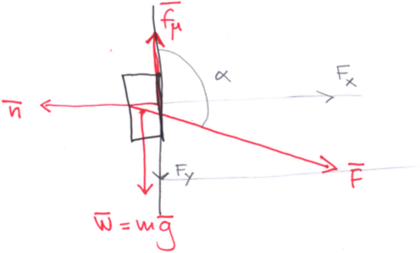
$$\rightarrow \sin\alpha = \mu_s \cos\alpha \rightarrow \frac{\sin\alpha}{\cos\alpha} = \mu_s$$

$$\rightarrow \tan(\alpha) = \mu_s$$

$$\rightarrow \alpha = \arctan(\mu_s)$$

d) Ef $\alpha > 90^\circ$ verður að ýta mjög fast til þess að bókin haldist kyrr

Fyrir hvaða horn $\alpha > 90^\circ$ er ekki hægt að halda lengur?



Enn heldur sama jafna

$$F = \frac{mg}{\cos\alpha + \mu_s \sin\alpha}$$

en nú þarf að muna að fyrir $\alpha > 90^\circ$ (og $\alpha < 180^\circ$) er $\cos\alpha < 0$, en $\sin\alpha > 0$

F er <u>lengd</u> kraftsins. Þurfum því núllstöðina í nefnaranum $\cos\alpha + \mu_s \sin\alpha = 0$ f. $90^\circ < \alpha < 180^\circ$

Skilgreinum $\alpha = 90° + \beta$ og finnum β

$$\alpha = \frac{\pi}{2} + \beta$$

$$\cos\alpha = \cos\left(\frac{\pi}{2}+\beta\right) = -\sin\beta$$

$$\sin\alpha = \sin\left(\frac{\pi}{2}+\beta\right) = \cos\beta$$

$$\rightarrow \cos\alpha + \mu_s \sin\alpha = -\sin\beta + \mu_s \cos\beta = 0$$

$$\rightarrow \frac{\sin\beta}{\cos\beta} = \mu_s \qquad \rightarrow \qquad \beta = \arctan(\mu_s)$$

fyrir enn stærri horn er ekki hægt að halda bókinni lengur

Reynið þessar niðurstöður í tilraun....

Fall hlutar í föstu þyngdarsviði í efni

T.d. fall hlutar í lofti ..... vökvaaflfræði . . . .

Einfölduð líkön

① við lágan hraða $\quad f = kv$

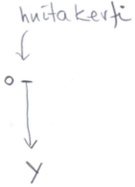
② háan hraða $\quad f = Dv^2$

í réttu hlutfalli við v

k og D eru fastar sem ákvarða má í tilraun eða flóknari líkönum

Reynum líkan ①

Kraftvogi



$$mg - kv_y = ma_y$$

hreyfijafna

$$ma_y = mg - kv_y$$

$$m\dot{v}_y = mg - kv_y$$

Hreyfijafnan gefur til kynna að hröðun stöðvist þegar hraðinn vex $\longrightarrow$ hraðinn stefnir á markgildi markhraði

$$0 = mg - kv_t \longrightarrow \boxed{v_t = \frac{mg}{k}}$$

Athugum hvernig hraðinn þróast með tíma

$$m\dot{v}_y = mg - kv_y \longrightarrow \dot{v}_y = g - \frac{kv_y}{m}$$

$$= g - g\frac{v_y}{v_t}$$

$$\frac{dv_y}{dt} = \frac{g}{v_t}\left[v_t - v_y\right] \quad \rightarrow \quad \frac{dv_y}{v_t - v_y} = \frac{g}{v_t}\,dt$$

eða

$$\frac{dv_y}{v_y - v_t} = -\frac{g}{v_t}\,dt$$

Sem hægt er að leiða beint, því við höfum einangrað t og v_y sitt hvoru megin

$$\int_0^{v} \frac{dv_y}{v_y - v_t} = -\frac{g}{v_t}\int_0^{t} dt'$$

upphafshraði

upphafstími

við viljum finna v við t.

$$\ln\left\{v_y - v_t\right\}\Big|_0^{v} = -\frac{g}{v_t}(t-0) \quad \rightarrow \quad \ln\left[\frac{v - v_t}{-v_t}\right] = -\frac{g}{v_t}\,t$$

$$1 - \frac{v}{v_t} = \exp\left\{-\frac{gt}{v_t}\right\}$$

$$\to \quad v = v_t\left[1 - \exp\left(-\frac{gt}{v_t}\right)\right]$$

possitivt hvertfor p. $t \to +\infty$

$$\lim_{t\to\infty} v(t) = v_t$$

eins og sást áður

Og likan ② $f = Dv^2$

$$m\dot{v}_y = mg - Dv_y^2 \quad \to \quad \dot{v}_y = g\left\{1 - \frac{v_y^2}{v_t^2}\right\} = \frac{g}{v_t^2}\left\{v_t^2 - v_y^2\right\}$$

þar sem núna fæst $v_t = \sqrt{\frac{mg}{D}}$

því þurfum við að heilda

$$\int_0^v \frac{dv_y}{v_y^2 - v_t^2} = -\frac{g}{v_t^2}\int_0^t dt'$$

$$\rightarrow \quad \frac{1}{2v_t}\ln\left\{\frac{v_t - v}{v + v_t}\right\} = -\frac{g}{v_t^2}\,t$$

$$\rightarrow \quad \frac{v_t - v}{v + v_t} = \exp\left\{-\frac{2gt}{v_t}\right\}$$

$$\rightarrow \quad v = v_t\left\{\frac{e^{+\frac{gt}{v_t}} - e^{-\frac{gt}{v_t}}}{e^{+\frac{gt}{v_t}} + e^{-\frac{gt}{v_t}}}\right\} = v_t \tanh\left(\frac{gt}{v_t}\right)$$

Berum saman á grafi þó v_t hafi ekki sömu merkingu. Athugið stölum til ~~þess~~ að fá víddarlausar stærðir fyrir grafið.

Lærdómur

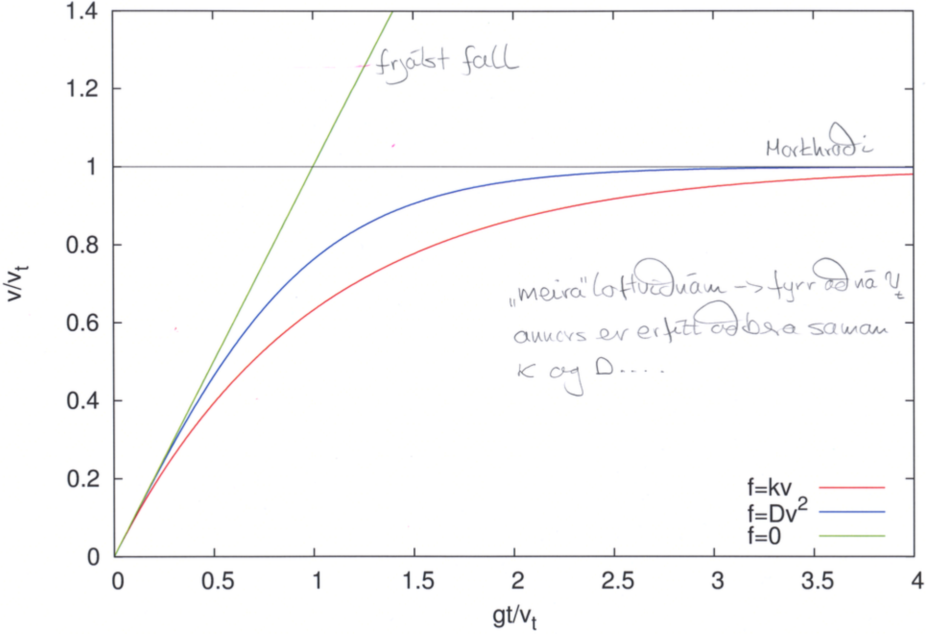
Bæði líkön leiða til markhraða

(1) $v_t = \frac{mg}{k}$

(2) $v_t = \sqrt{\frac{mg}{D}}$

markhraðinn er háður m !!

Án loftmótstöðu er fallhraðinn óháður m


frjálst fall
Markhraði
„meira" loftviðnám -> fyrr að ná v_t
annars er erfitt að bera saman
k og D....
f=kv
f=Dv^2
f=0
v/v_t
gt/v_t
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0.5
1.5
2
2.5
3
3.5
4