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The Study of the Motion of A Sinking or Rising Body in A Liquid, Taking into Account The Resistance of the Medium and Solving Related Problems

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Annotation: *This article examines the laws of motion of a body in a vertical plane under the action of the fluid resistance force, the Archimedan force and gravity, and develops issues related to them.*

Key words: *acceleration; the equation of motion; the equation velocity; the equation of motion; force of resistance; Archimedean force; the force of gravity; to take an integral; limits of integral.*

ИЗУЧЕНИЕ ДВИЖЕНИЯ ПОГРУЖАЮЩЕГОСЯ ИЛИ ПОДНИМАЮЩЕГОСЯ ТЕЛА В ЖИДКОСТИ С УЧЕТОМ СОПРОТИВЛЕНИЯ СРЕДЫ И РЕШЕНИЕ СВЯЗАННЫХ С НИМ ЗАДАЧ

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Аннотация: *В этой статье исследуются законы движения тела в вертикальной плоскости под действием силы сопротивления жидкости, силы Архимеда и силы тяжести и разрабатываются вопросы, связанные с ними.*

Ключевые слова: *ускорение; уравнение движения; уравнение скорость; дифференциальное уравнение; сила сопротивления; сила Архимеда; сила тяжести; интегрирование; пределы интеграла.*

SUYUQLIKDA CHO'KAYOTGAN YOKI KO'TARILAYOTGAN JISMNING HARAKATINI MUHITNING QARSHILIGINI E'TIBORGA OLGAN HOLDA O'RGANISH VA UNGA DOIR MASALALAR YECHISH

M.B.Dusmuratov

Chirchiq davlat pedagogika universiteti dotsenti

Annotatsiya: *Ushbu maqolada суюқликнинг qarshilik kuchi, Архимед кучи ҳамда оғирлик кучи ta'siridagi жисмнинг вертикал tekislikdagi harakat qonunlari o'rganilgan va ularga oid masalalar ishlab ko'rsatilgan.*

Калит сўзлар: *тезланиши; ҳаракат тенгламаси; тезлик тенгламаси; дифференциал тенглама; қаршилик кучи; Архимед кучи; оғирлик кучи; интеграллаш; интеграл чегаралари.*

Ma'lumki, umumta'lim o'rta maktablarining yuqori sinflari hamda akademik litsey o'quvchilariga suyuqlikda harakatlanayotgan jismning harakatini o'rganishga oid mavzulari juda ham mukammal darajada yoritilmagan. Bunda odatda yoki suyuqlikning qarshiligi e'tiborga olinmaydi yoki o'rtacha o'zgarmas kuch sifatida e'tiboirga olinadi. Oliy ta'limning turiga qarab bunday mavzu yoki umuman o'qitish dasturiga kiritilmaydi yoki jiddiyroq o'rganilmaydi. Faqatgina ayrim texnika OTMlaridagin "Gidravlika" degan maxsus fandagina chuqurlashtirib o'rganiladi. Pedagogika OTMlarining "Fizika" mutaxassisligi yo'nalishlarida esa gidrostatika mavzulari tashlab ketilib, faqat gidrodinamika elementlari sifatida Bernulli qonuni, oqim uzluksizligi, oqim turlari va Puzeyl tenglamasi kabi mavzular o'rganiladi. Lekin, suyuqlikning qarshilik kuchi tezlikka bog'liq ravishda o'zgaradigan holat deyarli o'rganilmaydi.

Shuning uchun ham suyuqlikning qarshiligini hamda og'irlik va Arximed kuchlarini birgalikda e'tiborga olingan holdagi jismning harakatini o'rganish muhim va u talabalarni real vaziyatga ancha yaqinlashtiradi.

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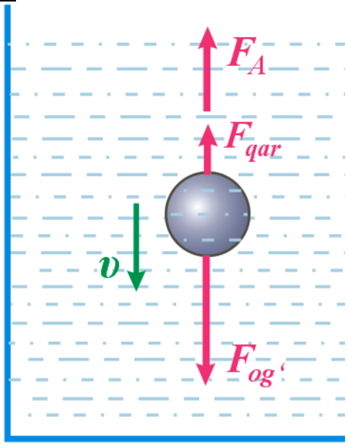
Bilamizki, muhitning qarshiligi tezlikning birinchi darajasiga yoki ikkinchi darajasiga to‘g‘ri proporsional bo‘lishi mukin. Masalan, suyuqlik bilan sodir bo‘ladigan hodisalarda (qayiq uoki kemaning harakatini o‘rganishda) qarshilik kuchi tezlikning birinchi darajasiga proporsional bo‘lsa, havo bilan sodir bo‘ladigan hodisalarda (avtomobil harakatini o‘rganishda, aviatsiyada, harbiy texnikada parashyut, o‘q, snaryad va boshqalarni o‘rganishda) qarshilik kuchini tezlikning ikkinchi darajasiga proporsional bo‘ladi. Biz ushbu maqolada suyuqlik ichida to‘la botgan holda pastga cho‘kayotgan yoki tepaga qalqib chiqayotgan jismning vertikal harakatini qarshilik kuchini tezlikka proporsional $\left(F_{qar} \sim \vartheta\right)$ holda bog‘lab o‘rganamiz va ularga oid masalalar ishlaymiz.

Jismning suyuqlikda cho‘kayotgan va suyuqlik tubidan ko‘tarilayotgan holatlarini alohida-alohida qarab chiqaylik.

I.



I.1-rasm

Agar jism biror suyuqlikda cho‘kayotgan bo‘lsa, harakat pastga tomon yo‘nalgani uchun jismga ta’sir qiladigan qarshilik kuchi tepaga yo‘naladi. Undan tashqari jismga tepaga yo‘nalgan Arximed kuchi va pastga yo‘nalgan og‘irlik kuchi ham ta’sir qiladi (I.1-rasm). Jism mana shu uchta kuch ta’sirida yoki tezlanubchan yoki sekinlanuvchan harakat bilan pastga tomon harakatlanayotgan bo‘lsin. Dinamikaning asosiy tenglamasini qo‘llab differensial tenglama hosil qilamiz hamda hosil bo‘lgan differensial tenglamani yechish orqali vaqt, tezlik, yo‘l orasidagi bog‘lanishlarni hosil qilishimiz mumkin bo‘ladi.

$$ma = F_{og'} - F_{qar} - F_A, \rightarrow \ m\frac{d\vartheta}{dt} = mg - \alpha\vartheta - F_A, \rightarrow \ dt = \frac{md\vartheta}{mg - \alpha\vartheta - F_A} = -\frac{m}{\alpha}\cdot\frac{d\vartheta}{\vartheta - \dfrac{mg - F_A}{\alpha}}$$

$$\int_0^t dt = -\frac{m}{\alpha}\cdot\int_{\vartheta_0}^{\vartheta}\frac{d\vartheta}{\vartheta - \dfrac{mg-F_A}{\alpha}}, \ \rightarrow \ t = -\frac{m}{\alpha}\cdot\ln\left|\vartheta - \frac{mg-F_A}{\alpha}\right|\Bigg|_{\vartheta_0}^{\vartheta} = -\frac{m}{\alpha}\cdot\ln\left|\frac{\vartheta - \dfrac{mg-F_A}{\alpha}}{\vartheta_0 - \dfrac{mg-F_A}{\alpha}}\right| =$$

$$= \frac{m}{\alpha}\cdot\ln\left|\frac{\vartheta_0 - \dfrac{mg-F_A}{\alpha}}{\vartheta - \dfrac{mg-F_A}{\alpha}}\right| = \frac{m}{\alpha}\cdot\ln\left|\frac{\alpha\vartheta_0 + F_A - mg}{\alpha\vartheta + F_A - mg}\right| = \frac{m}{\alpha}\cdot\ln\left|\frac{mg - (\alpha\vartheta_0 + F_A)}{mg - (\alpha\vartheta + F_A)}\right|$$

Shunday qilib biz suyuqlikka cho‘kayotgan jism uchun biror tezlikka erishish vaqtini aniqlovchi, ya’ni $t = t(\vartheta)$ ko‘rinishdagi tenglamani hosil qildik.

$$t = \frac{m}{\alpha}\cdot\ln\left|\frac{mg - (\alpha\vartheta_0 + F_A)}{mg - (\alpha\vartheta + F_A)}\right| \qquad \textbf{(I.1)}$$

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(I.1) formuladan foydalanib, tinch holatdan boshlab cho‘kishni boshlagan jism uchun quyidagi xususiy formulani olish mumkin:

$$t = \frac{m}{\alpha} \cdot \ln\left|\frac{mg - F_A}{mg - (\alpha\vartheta + F_A)}\right| \quad \textbf{(I.1a)}$$

Agar (I.1) formulada $mg < F_A$ bo‘lsa, cho‘kish jarayoni sekinlanuvchan, aksincha $mg > F_A$ bo‘lsa, cho‘kish jarayoni tezlanuvchan bo‘ladi. Agar jism sekinlanuvchan harakat qilayotgan bo‘lsa, u holda jism biror vaqtdan so‘ng to‘xtaydi. Bunda to‘xtash vaqti quyidagicha bo‘ladi:

$$t_{to'xt} = \frac{m}{\alpha} \cdot \ln\left|1 + \frac{\alpha\vartheta_0}{F_A - mg}\right| \quad \textbf{(I.1b)}$$

Endi tezlikning vaqtga bog‘lanish formulasini hosil qilamiz.

$$t = -\frac{m}{\alpha} \cdot \ln\left|\frac{\vartheta - \frac{mg - F_A}{\alpha}}{\vartheta_0 - \frac{mg - F_A}{\alpha}}\right|, \ \rightarrow \ \frac{\vartheta - \frac{mg - F_A}{\alpha}}{\vartheta_0 - \frac{mg - F_A}{\alpha}} = e^{-\frac{\alpha}{m}t}, \ \rightarrow \ \vartheta - \frac{mg - F_A}{\alpha} =$$

$$= \left(\vartheta_0 - \frac{mg - F_A}{\alpha}\right)e^{-\frac{\alpha}{m}t}, \ \rightarrow \ \vartheta = \left(\vartheta_0 - \frac{mg - F_A}{\alpha}\right)e^{-\frac{\alpha}{m}t} + \frac{mg - F_A}{\alpha}$$

$$\vartheta = \left(\vartheta_0 - \frac{mg - F_A}{\alpha}\right)e^{-\frac{\alpha}{m}t} + \frac{mg - F_A}{\alpha} \quad \textbf{(I.2)}$$

Yuqoridagi (I.2) formulada t→∞ bo‘lganda bitta had qoladi va bu erishish mumkinbo‘lgan maksimal tezlikni beradi.

$$\vartheta_{\max} = \frac{mg - F_A}{\alpha} \quad \textbf{(I.3)}$$

(I.3) formulani dinamikaning asosiy tenglamasidan ham hosil qilish mumkin.

$$ma = F_{og'} - F_{qar} - F_A = 0, \ \rightarrow \ F_{qar} = F_{og'} - F_A, \ \rightarrow \ \alpha\vartheta = mg - F_A, \ \rightarrow \ \vartheta_{\max} = \frac{mg - F_A}{\alpha}$$

Agar (I.3) formulani e’tiborga oladigan bo‘lsak, u holda (I.1) va (I.2) formulalarni maksimal tezlik orqali quyidagicha yozishimiz mumkin:

$$t = \frac{m}{\alpha} \cdot \ln\left|\frac{\vartheta_{\max} - \vartheta_0}{\vartheta_{\max} - \vartheta}\right| \quad \textbf{(I.1')}$$

$$\vartheta = \vartheta_{\max} - \left(\vartheta_{\max} - \vartheta_0\right)e^{-\frac{\alpha}{m}t} \quad \textbf{(I.2')}$$

Endi esa I.1-rasmdagi holat uchun yo‘l va tezlik orasidagi bog‘lanishni, ya’ni s=s(ϑ) tenglamani hosil qilaylik. Buning uchun yuqorida keltirib chiqarilgan tenglamalar kabi dinamikaning asosiy tenglamasidan foydalanib differensial tenglama hosil qilamiz va uni yechib chiqamiz.

$$m\frac{d\vartheta}{dt} = mg - \alpha\vartheta - F_A, \ \rightarrow \ m\frac{\vartheta d\vartheta}{ds} = mg - \alpha\vartheta - F_A, \ \rightarrow \ ds = \frac{m\vartheta d\vartheta}{mg - \alpha\vartheta - F_A} =$$

$$= -\frac{m}{\alpha} \cdot \frac{\vartheta\, d\vartheta}{\vartheta - \frac{mg - F_A}{\alpha}} = -\frac{m}{\alpha} \cdot \left(1 + \frac{\frac{mg - F_A}{\alpha}}{\vartheta - \frac{mg - F_A}{\alpha}}\right)d\vartheta.$$

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$$s=\int_0^s ds=-\frac{m}{\alpha}\cdot\int_{\vartheta_0}^{\vartheta}\left(1+\frac{\frac{mg-F_A}{\alpha}}{\vartheta-\frac{mg-F_A}{\alpha}}\right)d\vartheta=-\frac{m}{\alpha}\cdot\left[\vartheta+\frac{mg-F_A}{\alpha}\cdot\ln\left|\vartheta-\frac{mg-F_A}{\alpha}\right|\right]\Bigg|_{\vartheta_0}^{\vartheta}=$$

$$=-\frac{m}{\alpha}\cdot\left[\vartheta-\vartheta_0+\frac{mg-F_A}{\alpha}\cdot\ln\left|\frac{\vartheta-\frac{mg-F_A}{\alpha}}{\vartheta_0-\frac{mg-F_A}{\alpha}}\right|\right]=\frac{m}{\alpha}\cdot\left[\vartheta_0-\vartheta+\frac{mg-F_A}{\alpha}\cdot\ln\left|\frac{\alpha\vartheta_0+F_A-mg}{\alpha\vartheta+F_A-mg}\right|\right].$$

yoki

$$s=\frac{m}{\alpha}\cdot\left[\vartheta_0-\vartheta+\vartheta_{\max}\cdot\ln\left|\frac{\vartheta_{\max}-\vartheta_0}{\vartheta_{\max}-\vartheta}\right|\right]$$

Shunday qilib, s=s(ϑ) tenglamani hosil qildik.

$$s=\frac{m}{\alpha}\cdot\left[\vartheta_0-\vartheta+\frac{mg-F_A}{\alpha}\cdot\ln\left|\frac{\alpha\vartheta_0+F_A-mg}{\alpha\vartheta+F_A-mg}\right|\right] \quad \textbf{(I.3)}$$

$$s=\frac{m}{\alpha}\cdot\left[\vartheta_0-\vartheta+\vartheta_{\max}\cdot\ln\left|\frac{\vartheta_{\max}-\vartheta_0}{\vartheta_{\max}-\vartheta}\right|\right] \quad \textbf{(I.3')}$$

Yuqoridagi (I.3) va (I.3') formulalar jism ixtiyoriy ϑ tezlikka erishish uchun qanday s masofani bosib o‘tish kerakligini aniqlaydigan formulalardir.

Yuqoridagi (I.3) va (I.3') formulalardan foydalanib, tinch holatdan boshlab ($\vartheta_0=0$) cho‘kishni boshlagan jism uchun quyidagi xususiy formulani olish mumkin:

$$s=\frac{m}{\alpha}\cdot\left[\frac{mg-F_A}{\alpha}\cdot\ln\left|\frac{F_A-mg}{\alpha\vartheta+F_A-mg}\right|-\vartheta\right] \quad \textbf{(I.3a)}$$

$$s=\frac{m}{\alpha}\cdot\left[\vartheta_{\max}\cdot\ln\left|\frac{\vartheta_{\max}}{\vartheta_{\max}-\vartheta}\right|-\vartheta\right] \quad \textbf{(I.3'a)}$$

Agar $mg<F_A$ bo‘lsa, cho‘kish jarayoni sekinlanuvchan bo‘ladi, jism biror masofani bosib o‘tgach to‘xtaydi va Arximed kuchi ta’sirida yana tepaga qalqib chiqa boshlaydi. Bu holda yuqoridagi (I.3) va (I.3') formulalardan foydalanib to‘xtash vaqtini aniqlash mumkin bo‘ladi.

$$s_{to'xt}=\frac{m}{\alpha}\cdot\left[\vartheta_0+\frac{mg-F_A}{\alpha}\cdot\ln\left|1-\frac{\alpha\vartheta_0}{mg-F_A}\right|\right] \quad \textbf{(I.3b)}$$

$$s_{to'xt}=\frac{m}{\alpha}\cdot\left[\vartheta_0+\vartheta_{\max}\cdot\ln\left|1-\frac{\vartheta_0}{\vartheta_{\max}}\right|\right] \quad \textbf{(I.3'b)}$$

Shuni eslatib o‘tish kerakki, yuqoridagi 2ta formulada $\vartheta_{\max}=\frac{mg-F_A}{\alpha}<0$ bo‘ladi, ya’ni ϑ_{max} kattalikni manfiy ishorasini yoddan chiqarmaslik kerak.

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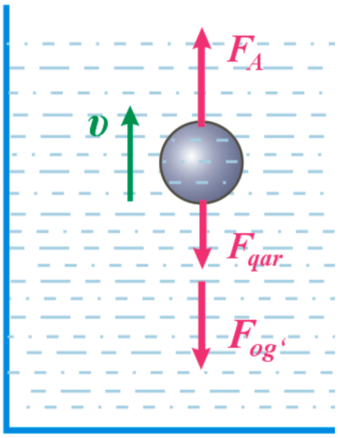
II.



II.1-rasm

Endi jism biror suyuqlikda suyuqlik tubidan Arximed kuchi va tepaga yo‘nalgan boshlang‘ich tezlik ta’sirida ko‘tarilayotgan bo‘lsin. Bunda harakat yuqoriga tomon yo‘nalgani uchun jismga ta’sir qiladigan qarshilik kuchi pastga yo‘naladi. Undan tashqari jismga tepaga yo‘nalgan Arximed kuchi va pastga yo‘nalgan og‘irlik kuchi ham ta’sir qiladi (II.1-rasm). Jism mana shu 3 ta kuch ta’sirida tezlanuvchan harakat bilan tepaga tomon harakatlanayotgan bo‘lsin. Dinamikaning asosiy tenglamasini qo‘llab differensial tenglama hosil qilamiz hamda hosil bo‘lgan differensial tenglamani yechish orqali vaqt, tezlik, yo‘l orasidagi bog‘lanishlarni hosil qilishimiz mumkin bo‘ladi.

$$ma = F_A - F_{og'} - F_{qar}, \;\rightarrow\; m\frac{d\vartheta}{dt} = F_A - mg - \alpha\vartheta, \;\rightarrow\; dt = \frac{md\vartheta}{F_A - mg - \alpha\vartheta} = -\frac{m}{\alpha}\cdot\frac{d\vartheta}{\vartheta - \dfrac{F_A - mg}{\alpha}}$$

$$\int_0^t dt = -\frac{m}{\alpha}\cdot\int_{\vartheta_0}^{\vartheta}\frac{d\vartheta}{\vartheta - \dfrac{F_A - mg}{\alpha}}, \;\rightarrow\; t = -\frac{m}{\alpha}\cdot\ln\left|\vartheta - \frac{F_A - mg}{\alpha}\right|\Bigg|_{\vartheta_0}^{\vartheta} = -\frac{m}{\alpha}\cdot\ln\left|\frac{\vartheta - \dfrac{F_A - mg}{\alpha}}{\vartheta_0 - \dfrac{F_A - mg}{\alpha}}\right| =$$

$$= \frac{m}{\alpha}\cdot\ln\left|\frac{\vartheta_0 - \dfrac{F_A - mg}{\alpha}}{\vartheta - \dfrac{F_A - mg}{\alpha}}\right| = \frac{m}{\alpha}\cdot\ln\left|\frac{\alpha\vartheta_0 + mg - F_A}{\alpha\vartheta + mg - F_A}\right|$$

Shunday qilib biz suyuqlik tubidan ko‘tarilayotgan jism uchun biror tezlikka erishish vaqtini aniqlovchi, ya’ni $t=t(\vartheta)$ ko‘rinishdagi tenglamani hosil qildik.

$$t = \frac{m}{\alpha}\cdot\ln\left|\frac{\alpha\vartheta_0 + mg - F_A}{\alpha\vartheta + mg - F_A}\right| \qquad \textbf{(II.1)}$$

(II.1) formuladan foydalanib, tinch holatdan boshlab ko‘tarilishni boshlagan jism uchun quyidagi xususiy formulani olish mumkin:

$$t = \frac{m}{\alpha}\cdot\ln\left|\frac{mg - F_A}{\alpha\vartheta + mg - F_A}\right| \qquad \textbf{(II.1a)}$$

Agar (II.1) formulada $mg > F_A$ bo‘lsa, ko‘tarilish jarayoni sekinlanuvchan, aksincha $mg < F_A$ bo‘lsa, ko‘tarilish jarayoni tezlanuvchan bo‘ladi. Agar jism sekinlanuvchan harakat qilayotgan bo‘lsa, u holda jism biror vaqtdan so‘ng to‘xtaydi va yana pastga cho‘ka boshlaydi. Bunda to‘xtash vaqti quyidagicha bo‘ladi:

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$$t_{to'xt} = \frac{m}{\alpha} \cdot \ln\left|1 + \frac{\alpha \vartheta_0}{mg - F_A}\right| \tag{II.1b}$$

Endi tezlikning vaqtga bog‘lanish formulasini hosil qilamiz.

$$t = -\frac{m}{\alpha} \cdot \ln\left|\frac{\vartheta - \dfrac{F_A - mg}{\alpha}}{\vartheta_0 - \dfrac{F_A - mg}{\alpha}}\right|, \quad \rightarrow \quad \frac{\vartheta - \dfrac{F_A - mg}{\alpha}}{\vartheta_0 - \dfrac{F_A - mg}{\alpha}} = e^{-\frac{\alpha}{m}t}, \quad \rightarrow \quad \vartheta - \frac{F_A - mg}{\alpha} =$$

$$= \left(\vartheta_0 - \frac{F_A - mg}{\alpha}\right) e^{-\frac{\alpha}{m}t}, \quad \rightarrow \quad \vartheta = \left(\vartheta_0 - \frac{F_A - mg}{\alpha}\right) e^{-\frac{\alpha}{m}t} + \frac{F_A - mg}{\alpha}$$

$$\vartheta = \left(\vartheta_0 - \frac{F_A - mg}{\alpha}\right) e^{-\frac{\alpha}{m}t} + \frac{F_A - mg}{\alpha} \tag{II.2}$$

Yuqoridagi (II.2) formulada t→∞ bo‘lganda bitta had qoladi va bu erishish mumkin bo‘lgan maksimal tezlikni beradi.

$$\vartheta_{\max} = \frac{F_A - mg}{\alpha} \tag{II.3}$$

(II.3) formulani dinamikaning asosiy tenglamasidan ham hosil qilish mumkin.

$$ma = F_A - F_{og'} - F_{qar} = 0, \ \rightarrow \ F_{qar} = F_A - F_{og'}, \ \rightarrow \ \alpha\vartheta = F_A - mg, \ \rightarrow \ \vartheta_{\max} = \frac{F_A - mg}{\alpha}$$

Agar (II.3) formulani e’tiborga oladigan bo‘lsak, u holda (II.1) va (II.2) formulalarni maksimal tezlik orqali quyidagicha yozishimiz mumkin:

$$t = \frac{m}{\alpha} \cdot \ln\left|\frac{\vartheta_{\max} - \vartheta_0}{\vartheta_{\max} - \vartheta}\right| \tag{II.1'}$$

$$\vartheta = \vartheta_{\max} - \left(\vartheta_{\max} - \vartheta_0\right) e^{-\frac{\alpha}{m}t} \tag{II.2'}$$

Endi esa II.1-rasmdagi holat uchun yo‘l va tezlik orasidagi bog‘lanishni, ya’ni s=s(ϑ) tenglamani hosil qilaylik. Buning uchun yuqorida keltirib chiqarilgan tenglamalar kabi dinamikaning asosiy tenglamasidan foydalanib differensial tenglama hosil qilamiz va uni yechib chiqamiz.

$$m\frac{d\vartheta}{dt} = F_A - mg - \alpha\vartheta, \ \rightarrow \ m\frac{\vartheta d\vartheta}{ds} = F_A - mg - \alpha\vartheta, \ \rightarrow \ ds = \frac{m\vartheta d\vartheta}{F_A - mg - \alpha\vartheta} =$$

$$= -\frac{m}{\alpha} \cdot \frac{\vartheta d\vartheta}{\vartheta - \dfrac{F_A - mg}{\alpha}} = -\frac{m}{\alpha} \cdot \left(1 + \frac{\dfrac{F_A - mg}{\alpha}}{\vartheta - \dfrac{F_A - mg}{\alpha}}\right) d\vartheta.$$

$$s = \int_0^s ds = -\frac{m}{\alpha} \cdot \int_{\vartheta_0}^{\vartheta} \left(1 + \frac{\dfrac{F_A - mg}{\alpha}}{\vartheta - \dfrac{F_A - mg}{\alpha}}\right) d\vartheta = -\frac{m}{\alpha} \cdot \left[\vartheta + \frac{F_A - mg}{\alpha} \cdot \ln\left|\vartheta - \frac{F_A - mg}{\alpha}\right|\right] \Bigg|_{\vartheta_0}^{\vartheta} =$$

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$$= -\frac{m}{\alpha}\cdot\left[\vartheta-\vartheta_0+\frac{F_A-mg}{\alpha}\cdot\ln\left|\frac{\vartheta-\frac{F_A-mg}{\alpha}}{\vartheta_0-\frac{F_A-mg}{\alpha}}\right|\right]=\frac{m}{\alpha}\cdot\left[\vartheta_0-\vartheta+\frac{F_A-mg}{\alpha}\cdot\ln\left|\frac{\alpha\vartheta_0+mg-F_A}{\alpha\vartheta+mg-F_A}\right|\right].$$

yoki

$$s=\frac{m}{\alpha}\cdot\left[\vartheta_0-\vartheta+\vartheta_{\max}\cdot\ln\left|\frac{\vartheta_{\max}-\vartheta_0}{\vartheta_{\max}-\vartheta}\right|\right]$$

Shunday qilib, s=s(ϑ) tenglamani hosil qildik.

$$s=\frac{m}{\alpha}\cdot\left[\vartheta_0-\vartheta+\frac{F_A-mg}{\alpha}\cdot\ln\left|\frac{\alpha\vartheta_0+mg-F_A}{\alpha\vartheta+mg-F_A}\right|\right] \quad \textbf{(II.4)}$$

$$s=\frac{m}{\alpha}\cdot\left[\vartheta_0-\vartheta+\vartheta_{\max}\cdot\ln\left|\frac{\vartheta_{\max}-\vartheta_0}{\vartheta_{\max}-\vartheta}\right|\right] \quad \textbf{(II.4')}$$

Yuqoridagi (II.4) va (II.4') formulalar jism ixtiyoriy ϑ tezlikka erishish uchun qanday s masofani bosib o‘tish kerakligini aniqlaydigan formulalardir.

Yuqoridagi (II.4) va (II.4') formulalardan foydalanib, tinch holatdan boshlab ($\vartheta_0=0$) ko‘tarilishni boshlagan jism uchun quyidagi xususiy formulani olish mumkin:

$$s=\frac{m}{\alpha}\cdot\left[\frac{F_A-mg}{\alpha}\cdot\ln\left|\frac{mg-F_A}{\alpha\vartheta+mg-F_A}\right|-\vartheta\right] \quad \textbf{(II.4a)}$$

$$s=\frac{m}{\alpha}\cdot\left[\vartheta_{\max}\cdot\ln\left|\frac{\vartheta_{\max}}{\vartheta_{\max}-\vartheta}\right|-\vartheta\right] \quad \textbf{(II.4'a)}$$

Agar $mg > F_A$ bo‘lsa, ko‘tarilish jarayoni sekinlanuvchan bo‘ladi, jism biror masofani bosib o‘tgach to‘xtaydi va og‘irlik kuchi ta’sirida pastga cho‘ka boshlaydi. Bu holda yuqoridagi (II.4) va (II.4') formulalardan foydalanib to‘xtash vaqtini aniqlash mumkin bo‘ladi.

$$s_{to'xt}=\frac{m}{\alpha}\cdot\left[\vartheta_0+\frac{F_A-mg}{\alpha}\cdot\ln\left|1-\frac{\alpha\vartheta_0}{F_A-mg}\right|\right] \quad \textbf{(II.4b)}$$

$$s_{to'xt}=\frac{m}{\alpha}\cdot\left[\vartheta_0+\vartheta_{\max}\cdot\ln\left|1-\frac{\vartheta_0}{\vartheta_{\max}}\right|\right] \quad \textbf{(II.4'b)}$$

Shuni eslatib o‘tish kerakki, yuqoridagi 2ta formulada $\vartheta_{\max}=\frac{F_A-mg}{\alpha}<0$ bo‘ladi, ya’ni ϑ_{max} kattalikni manfiy ishorasini yoddan chiqarmaslik kerak.

III. Endi esa yuqorida keltirib chiqarilgan barcha formulalar yuzasidan bir necha masalalar ishlash orqali bilimlarimizni mustahkamlab olamiz.

1-masala: Massasi $m=10\ g$ ga teng bo‘lgan alyuminiy sharcha $t=0{,}5\ s$ vaqtda idish tubiga yetib borgan bo‘lsa, u qanday tezlik bilan tushgan? Bu tezlik erishish mumkin bo‘lgan maksimal tezlikning qanday qismini tashkil etadi? Idishning chuqurligi nimaga teng? Alyuminiyning zichligi $\rho_{al}=2700\ \frac{kg}{m^3}$ ga, suvniki esa $\rho_{suv}=1000\ \frac{kg}{m^3}$ ga

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teng. Suvning berilgan alyuminiy sharchaga qarshilik koeffitsiyentini $\alpha = 3\cdot 10^{-4}\frac{kg}{s}$ deb, erkin tushish tezlanishini esa $g = 9,8\ m/s^2$ deb oling.

Yechish: Masala shartidan foydalanib sharchaga ta'sir qiladigan Arximed kuchini aniqlaymiz.

$$F_A = \rho_{suv} V g = \frac{\rho_{suv}}{\rho_{al}} mg = \frac{1000\frac{kg}{m^3}}{2700\frac{kg}{m^3}}\cdot 0,01 kg\cdot 9,8\frac{m}{s^2} = 0,0363\,N$$

Yuqorida keltirib chiqarilgan (I.2) formuladan foydalanamiz. Bunda boshlang'ich tezlikni $\vartheta_0 = 0$ deb olamiz.

$$\vartheta = \left(\vartheta_0 - \frac{mg - F_A}{\alpha}\right)e^{-\frac{\alpha}{m}t} + \frac{mg - F_A}{\alpha} = \frac{mg - F_A}{\alpha}\left(1 - e^{-\frac{\alpha}{m}t}\right) =$$

$$= \frac{0,01kg\cdot 9,8\frac{m}{s^2} - 0,0363\,N}{3\cdot 10^{-4}\frac{kg}{s}}\cdot\left(1 - e^{-\frac{3\cdot 10^{-4}\frac{kg}{s}}{0,01kg}\cdot 0,5\,s}\right) = 207\frac{m}{s}\cdot(1 - 0,985) = 3,1\frac{m}{s}$$

Bu tezlik erishish mumkin bo'lgan maksimal $\vartheta_{\max} = \frac{mg - F_A}{\alpha} = 207\frac{m}{s}$ tezlikning $(1 - 0,985) = 0,015 = 1,5\%$ qismini tashkil etar ekan.

Idishning chuqurligini yuqorida keltirib chiqarilgan (I.3') formuladan foydalanib hisoblaymiz. Bunda boshlang'ich tezlikni $\vartheta_0 = 0$ deb olamiz.

$$s = \frac{m}{\alpha}\cdot\left[\vartheta_0 - \vartheta + \vartheta_{\max}\cdot\ln\left|\frac{\vartheta_{\max} - \vartheta_0}{\vartheta_{\max} - \vartheta}\right|\right] = \frac{m}{\alpha}\cdot\left[\vartheta_{\max}\cdot\ln\left|\frac{\vartheta_{\max}}{\vartheta_{\max} - \vartheta}\right| - \vartheta\right] =$$

$$= \frac{0,01kg}{3\cdot 10^{-4}\frac{kg}{s}}\cdot\left[207\frac{m}{s}\cdot\ln\left|\frac{207\frac{m}{s}}{207\frac{m}{s} - 3,1\frac{m}{s}}\right| - 3,1\frac{m}{s}\right] = 33,33\,s\cdot\left[207\frac{m}{s}\cdot 0,015089 - 3,1\frac{m}{s}\right] =$$

$$= 33,33\,s\cdot 0,2345\frac{m}{s} = 0,78\,m = 78\ cm.$$

2-masala: Massasi *m=100 mg* ga teng bo'lgan qo'rg'oshin sharcha glitserin suyuqligida qanday maksimal tezlikka erisha oladi? Suyuqlikning sharchaga qarshilik kuchini Stoks formulasi $F_{qar} = 6\pi\eta r\vartheta$ dan hisoblang. Qo'rg'oshinning zichligi $\rho_q = 11300\frac{kg}{m^3}$ ga, glitserinniki esa $\rho_s = 1260\frac{kg}{m^3}$ ga teng. Glitserinning 20^0C temperaturadagi dinamik qovushqoqligini $\eta = 1,5\,Pa\cdot s$ deb, erkin tushish tezlanishini esa $g = 9,8\ m/s^2$ deb oling.

Yechish: Masalani yechish uchun eng avvalo sharchaning radiusini aniqlab olish kerak. Jismning hajmi

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$$V = \frac{m}{\rho} = \frac{10^{-4} kg}{11300 \frac{kg}{m^3}} = 8,85 \cdot 10^{-9} m^3$$

ga teng. Sharchaning hajmini topish formulasidan foydalanib, sharcha radiusini aniqlaymiz.

$$V = \frac{4}{3}\pi r^3, \rightarrow \ r = \sqrt[3]{\frac{3V}{4\pi}} = \sqrt[3]{\frac{3 \cdot 8,85 \cdot 10^{-9} m^3}{4 \cdot 3,14}} = 0,001283 m = 1,283 mm$$

Endi qarshilik koeffitsiyenti α ni hisoblaylik. Suyuqlikning qarshilik kuchi bir tomondan $F_{qar} = \alpha \vartheta$ formuladan, boshqa tomondan esa Stoks formulasi $F_{qar} = 6\pi \eta r \vartheta$ dan hisoblanadi. Ularni tenglashtirish orqali α koeffitsiyentni aniqlashimiz mumkin.

$$\alpha = 6\pi \eta r = 6 \cdot 3,14 \cdot (1,5 Pa \cdot s) \cdot (1,283 \cdot 10^{-3} m) = 36,26 \cdot 10^{-3} \frac{kg}{s}$$

Navbatdagi hisob-kitob ishlarimizni Arximed kuchini aniqlashga qaratamiz.

$$F_A = \rho_s V g = \frac{\rho_s}{\rho_q} mg = \frac{1260 \frac{kg}{m^3}}{11300 \frac{kg}{m^3}} \cdot 10^{-4} kg \cdot 9,8 \frac{m}{s^2} = 1,093 \cdot 10^{-4} N$$

Endi esa berilgan qo‘rg‘oshin sharcha glitserinda cho‘kish mobaynida erishish mumkin bo‘lgan maksimal tezligini aniqlaymiz.

$$\vartheta_{\max} = \frac{mg - F_A}{\alpha} = \frac{10^{-4} kg \cdot 9,8 \frac{m}{s^2} - 1,093 \cdot 10^{-4} N}{3,626 \cdot 10^{-4} \frac{kg}{s}} = 2,4 \frac{m}{s}.$$

3-masala: Suyuqlik yuzida to‘la botib turgan radiusi *r=5 sm* ga teng bo‘lgan rezina sharchaga pastga yo‘nalgan $\vartheta_0 = 20 \frac{m}{s}$ boshlang‘ich tezlik berildi. Bu sharcha qancha chuqurlikkacha tushadi va otilgandan boshlab qancha vaqtdan keyin qaytib chiqadi? Rezina materialining zichligi $\rho_r = 600 \frac{kg}{m^3}$ ga, suvniki esa $\rho_s = 1000 \frac{kg}{m^3}$ ga teng, suv uchun dinamik qovushqoqlikni $\eta = 1\, mPa \cdot s$ ga teng. Erkin tushish tezlanishini esa $g = 9,8\, m/s^2$ deb oling.

Yechish: Eng avvalo rezina sharchaning massasini aniqlaymiz.

$$m = \rho V = \frac{4}{3}\pi \rho r^3 = \frac{4}{3} \cdot 3,14 \cdot \left(600 \frac{kg}{m^3}\right) \cdot (5 \cdot 10^{-2} m)^3 = 0,314 kg$$

Arximed kuchini aniqlaymiz.

$$F_A = \rho_s V g = \rho_s \frac{4}{3}\pi \rho r^3 g = 1000 \frac{kg}{m^3} \cdot \frac{4}{3} \cdot 3,14 \cdot (5 \cdot 10^{-2} m)^3 \cdot 9,8 \frac{m}{s^2} \approx 5,13 N$$

α qarshilik koeffitsiyentini aniqlaymiz.

$$\alpha = 6\pi \eta r = 6 \cdot 3,14 \cdot (10^{-3} Pa \cdot s) \cdot (5 \cdot 10^{-2} m) = 9,42 \cdot 10^{-4} \frac{kg}{s}$$

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Arximed kuchi og‘irlik kuchidan katta bo‘lgani uchun pastga otilgan rezina sharcha sekinlanuvchan harakat qilib biror chuqlikkacha tushib to‘xtaydi va Arximed kuchi ta’sirida yana tepaga qalqib chiqadi. Bu rezina sharchaning suvga botish chuqurligini aniqlash uchun (I.3) formuladan foydalanamiz. Bunda oxirgi tezlikni $\vartheta = 0$ deb olamiz.

$$s_{to'xt} = \frac{m}{\alpha}\cdot\left[\vartheta_0 - \vartheta + \frac{mg - F_A}{\alpha}\cdot\ln\left|\frac{\alpha\vartheta_0 + F_A - mg}{\alpha\vartheta + F_A - mg}\right|\right] = \frac{m}{\alpha}\cdot\left[\vartheta_0 + \frac{mg - F_A}{\alpha}\cdot\ln\left|1 + \frac{\alpha\vartheta_0}{F_A - mg}\right|\right] =$$

$$= \frac{0,314\,kg}{9,42\cdot 10^{-4}\,\frac{kg}{s}}\cdot\left[20\,\frac{m}{s} + \frac{0,314\,kg\cdot 9,8\,\frac{m}{s^2} - 5,13\,N}{9,42\cdot 10^{-4}\,\frac{kg}{s}}\cdot\ln\left|1 + \frac{9,42\cdot 10^{-4}\,\frac{kg}{s}\cdot 20\,\frac{m}{s}}{5,13\,N - 0,314\,kg\cdot 9,8\,\frac{m}{s^2}}\right|\right] =$$

$$= 333,333\ s\cdot\left[20\,\frac{m}{s} - 2179,2\,\frac{m}{s}\cdot\ln\left(1,0091778\right)\right] = 30,32\ m.$$

Pastga otilgan rezina sharchaning umumiy harakat vaqtini ikkiga bo‘lamiz. Sharchaning sekinlashib to‘xtash vaqti $t_{to'xt}$ hamda yana tepaga qalqib chiqish vaqti $t_{ko'tar}$ to‘xtash vaqtini aniqlaymiz.

$$t_{to'xt} = \frac{m}{\alpha}\cdot\ln\left|\frac{mg - (\alpha\vartheta_0 + F_A)}{mg - (\alpha\vartheta + F_A)}\right| = \frac{m}{\alpha}\cdot\ln\left|1 + \frac{\alpha\vartheta_0}{F_A - mg}\right| = \frac{0,314\,kg}{9,42\cdot 10^{-4}\,\frac{kg}{s}}\cdot$$

$$\cdot\ln\left|1 + \frac{9,42\cdot 10^{-4}\,\frac{kg}{s}\cdot 20\,\frac{m}{s}}{5,13\,N - 0,314\,kg\cdot 9,8\,\frac{m}{s^2}}\right| = 333,333\ s\cdot\ln\left(1,0091778\right) = 3,0453\ s.$$

Sharcha to‘xtagan nuqtasidan tepaga tomon tezlanuvchan harakat qiladi. Tepaga qalqib chiqganda erishgan tezligini aniqlaymiz.

$$s = \frac{m}{\alpha}\cdot\left[\vartheta_0 - \vartheta + \frac{F_A - mg}{\alpha}\cdot\ln\left|\frac{\alpha\vartheta_0 + mg - F_A}{\alpha\vartheta + mg - F_A}\right|\right] = \frac{m}{\alpha}\cdot\left[\frac{F_A - mg}{\alpha}\cdot\ln\left|\frac{mg - F_A}{\alpha\vartheta + mg - F_A}\right| - \vartheta\right]$$

Yuqoridagi tenglamadan tezlik ϑ ni aniqlab olish formulasini tuzib bo‘lmaydi. Chunki tezlik ϑ logarifmning ichida ham tashqarisida ham kelgan. Buni ishlash uchun s=s(ϑ) grafikni chizib, so‘ng u yerdan $s = s_{to'xt} = 30,32\ m$ ga teng qiymatga mos kelgan ϑ tezlik qiymatini aniqlaymiz. s=s(ϑ) grafik III.1-rasmda tasvirlangan.

Rasmdan ko‘rinadiki, $\vartheta \approx 19,85\frac{m}{s}$ da $s = s_{to'xt} = 30,32\ m$ ga teng bo‘lar ekan.

Endi sharcha tushgan chuqurlikdan tepagacha chiqish vaqtini aniqlaymiz. Buning uchun (II.1) formuladan foydalanamiz. Bunda boshlang‘ich tezlikni $\vartheta_0 = 0$ deb olamiz.

$$t_{ko'tar} = \frac{m}{\alpha}\cdot\ln\left|\frac{\alpha\vartheta_0 + mg - F_A}{\alpha\vartheta + mg - F_A}\right| = \frac{m}{\alpha}\cdot\ln\left|\frac{mg - F_A}{\alpha\vartheta + mg - F_A}\right| = \frac{0,314\,kg}{9,42\cdot 10^{-4}\,\frac{kg}{s}}\cdot$$

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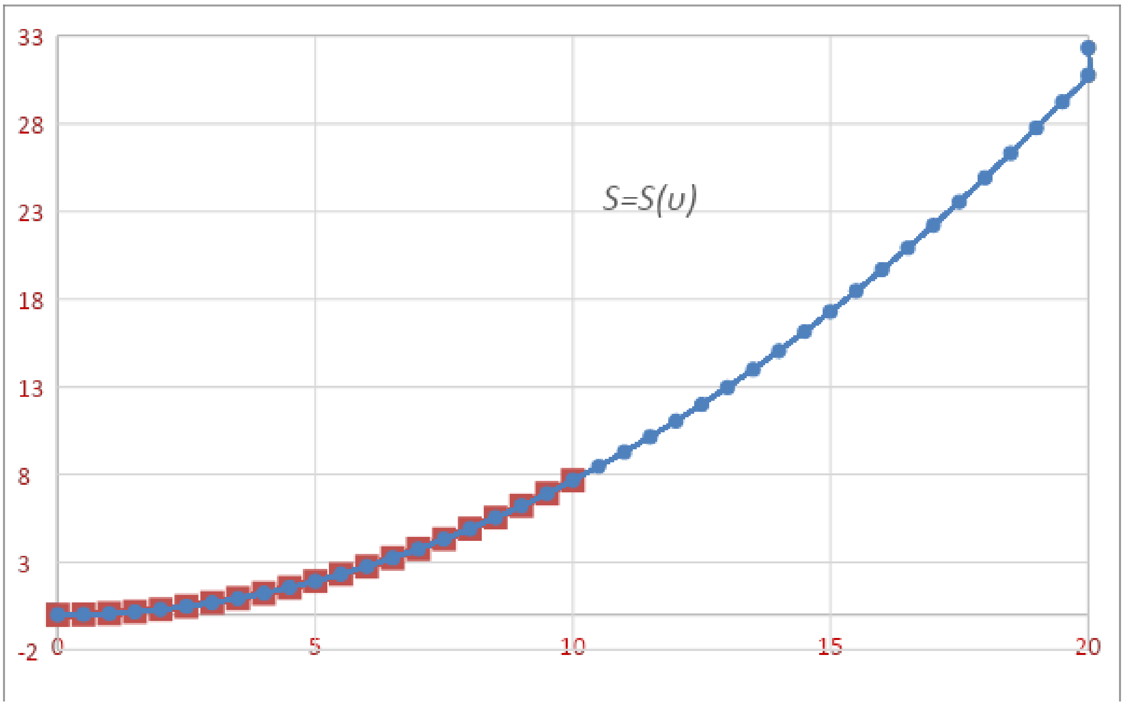
$$\cdot\ln\left|\frac{0,314\,kg\cdot 9,8\,\frac{m}{s^2}-5,13\,N}{9,42\cdot 10^{-4}\,\frac{kg}{s}\cdot 19,85\,\frac{m}{s}+0,314\,kg\cdot 9,8\,\frac{m}{s^2}-5,13\,N}\right|=$$

$$=333,333\;s\cdot\ln\left(1,00915061\right)=3,03633\;s$$



III.1-rasm

Umumiy vaqtni to‘xtash vaqti va ko‘tarilish vaqti yig‘indisi tashkil qiladi.

$$t_{umum}=t_{to'xt}+t_{ko'tar}=3,0423+3,03633=6,07863\;s$$

Shunday qilib biz so‘ralgan barcha kattaliklarni hisoblab chiqardik.

4-masala: Radiusi $r=1\;cm$ ga teng bo‘gan po‘kak kerosin tagidan ko‘tarilish davomida tezlanish qanday qonuniyat bo‘yicha sodir bo‘ladi. Maksimal tezlanishning qiymati nimaga teng? Qancha t vaqtdan keyin tezlanishning qiymati e marta kamayadi? Po‘kak materialining zichligi $\rho_p=200\,\frac{kg}{m^3}$ ga, kerosinniki esa $\rho_k=800\,\frac{kg}{m^3}$ ga teng, suv uchun dinamik qovushqoqlikni $\eta=1,5\;mPa\cdot s$ ga teng. Erkin tushish tezlanishini $g=9,8\;m/s^2$ deb oling.

Yechish: Tezlanishni aniqlash ishlash uchun yuqoridagi (II.2) formuladan foydalanamiz. Bunda boshlang‘ich tezlikni $\vartheta_0=0$ deb olamiz.

$$\vartheta=\left(\vartheta_0-\frac{F_A-mg}{\alpha}\right)e^{-\frac{\alpha}{m}t}+\frac{F_A-mg}{\alpha}=\frac{F_A-mg}{\alpha}\left(1-e^{-\frac{\alpha}{m}t}\right)$$

Yuqoridagi formuladan vaqt bo‘cha 1-tartibli hosila olamiz. Bunda tezlanishning vaqt bo‘yicha o‘zgarish tenglamasi hosil bo‘ladi.

$$a=\frac{d\vartheta}{dt}=\frac{F_A-mg}{\alpha}\cdot\frac{d}{dt}\left(1-e^{-\frac{\alpha}{m}t}\right)=\frac{mg-F_A}{\alpha}\cdot\frac{\alpha}{m}\cdot e^{-\frac{\alpha}{m}t}=\left(g-\frac{F_A}{m}\right)\cdot e^{-\frac{\alpha}{m}t}$$

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Yuqoridagi tenglamada Arximed kuchi uchun $F_A = \rho_k V g = \frac{4}{3}\pi\,\rho_k g\, r^3$ massa uchun $m = \rho_p V = \frac{4}{3}\pi\,\rho_p r^3$ va qarshilik koeffitsiyenti uchun $\alpha = 6\pi\,\eta\, r$ formulalardan foydalansak, ushbu ko'rinishga o'tamiz.

$$a = \left(g - \frac{F_A}{m}\right)\cdot e^{-\frac{\alpha}{m}t} = \left(g - \frac{\rho_k V g}{\rho_p V g}\right)\cdot e^{-\frac{6\pi\,\eta\, r}{\frac{4}{3}\pi\,\rho_p\, r^2}} = \frac{\rho_p - \rho_k}{\rho_p} g\cdot e^{-\frac{9\eta}{2\rho_p r^2}t}$$

Shunday qilib tezlanish vaqt bo'yicha

$$a(t) = \frac{\rho_p - \rho_k}{\rho_p} g\cdot e^{-\frac{9\eta}{2\rho_p r^2}t}$$

qonun bo'yicha sodir bo'lar ekan. Maksimal tezlanish

$$a = \frac{\rho_p - \rho_k}{\rho_p} g\cdot e^{-\frac{9\eta}{2\rho_p r^2}\cdot 0} = \frac{\rho_p - \rho_k}{\rho_p} g = \frac{200\,\frac{kg}{m^3} - 800\,\frac{kg}{m^3}}{200\,\frac{kg}{m^3}}\cdot 9{,}8\,\frac{m}{s^2} = -29{,}4\,\frac{m}{s^2}$$

Tezlanish *e* marta kamayish uchun *a=a(t)* tenglamada eksponenta darajasi *1* ga teng bo'lishi kerak.

$$\frac{9\eta}{2\rho_p r^2}t = 1, \;\rightarrow\; t = \frac{2\rho_p r^2}{9\eta} = \frac{2\cdot 200\frac{kg}{m^3}\cdot\left(10^{-2}m\right)^2}{9\cdot 1{,}5\cdot 10^{-3}\,Pa\cdot s} = 2{,}963\ s$$

Biz ushbu maqolada talabalarga umumiy tushunchalar berish maqsadida suyuqlikda cho'kayotgan yoki ko'tarilayotgan jismga qarshilikli muhitning ta'sirini va bundagi harakat va tezlik tenglamalarini o'rgandik. Buna suyuqlikning qarshiligini tezlikning 1-darajasiga proporsional deb oldik.

Qarshilikli muhitda jismning harakatini o'rganishda, biz jismdagi qarshilik kuchini va shuning uchun jismning tezlik o'zgarishini uning tezligining biror funksiyasi deb hisoblaymiz. Bunday qarshilik kuchlari odatda konservativ emas va kinetik energiya odatda ichki energiyaga aylanadi. Bunday mavzuni o'rganish hamda ularga oid masalalar yechish talabalarni ob'ektiv reallikka yaqinlashtiradi hamda tasavvur qila olish qobiliyatini o'stiradi, shuningdek differensial va intgeral hisob-kitob ishlariga ko'nikma hosil qilishda yordam beradi.

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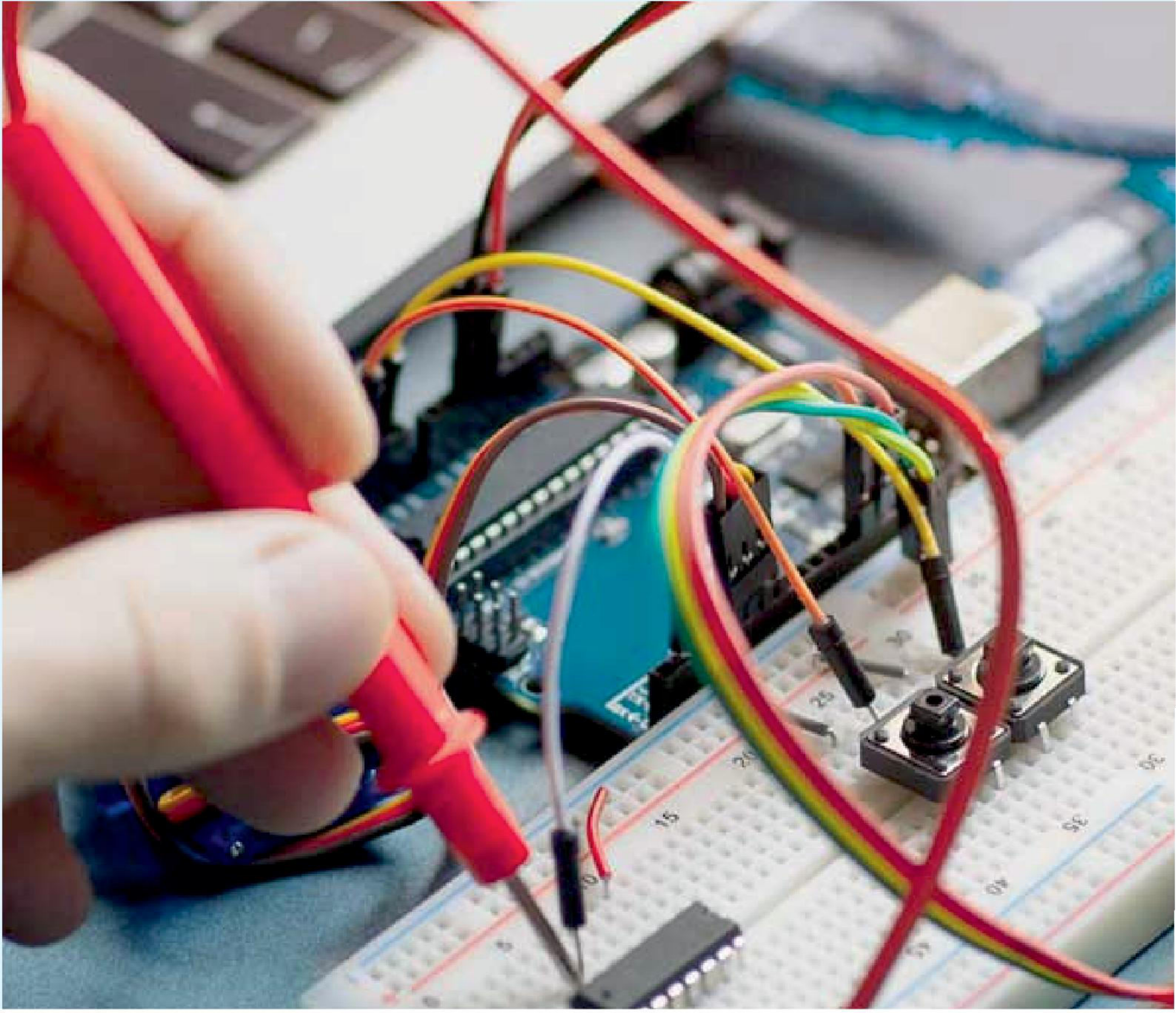

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