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BIR TO‘G‘RI CHIZIQDA JOYLASHGAN ZARYADLAR SISTEMASINI MUNTAZAM KO‘PBURCHAK SHAKLGA KELTIRISHDA BAJARGAN ISHINI HISOBLASH METODIKASI

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Annotatsiya
Ushbu maqolada bir to‘g‘ri chiziqda joylashgan zaryadlar sistemasini muntazam ko‘pburchak shaklga keltirishda bajargan ishini topish masalasi ko‘rib otilgan.

Kalit so‘zlar
Nuqtaviy zaryad, zaryadlar sistemasining potensial energiyasi, elektr maydon potensiali, zaryadni ko‘chirishda bajarilgan ish.

Аннотация
В данной работе рассматривается задача нахождения работы по приведению нескольких точечных зарядов, находящихся на одной прямой в правильный многоугольник.

Ключевые слова
Точечный заряд, потенциальная энергия системы зарядов, потенциал электрического поля, работа по перемещению заряда.

Abstract
This paper considers the problem of finding the work of bringing several point charges lying on the same straight line into a regular polygon.

Key words
electric charge, potential energy of a system of charges, electric field potential, work to move a charge.

Oliy ta’lim muassasalarida talabalar elektr va magnetism bo‘yicha masalalar yechishda ko‘pgina qiyinchiliklarga duch kelishadi. Sababi o‘rta maxsus ta’limda yetarlicha bilim olishmaydi. Natijada oily ta’limda o‘qiyotgan vaqtlarida murakkabroq masalalarni yecha olishmaydi. Shuning uchun yuqori malakali fizik o‘qituvchi kadrlar yetishtirib chiqarishda ba’zi muammolar tug‘iladi. Ularni

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bartaraf etish uchun talabalar turli xil qiyinlikdagi masalalarni yechishga o‘rganishlari kerak.

Ushbu maqolada fizikaning eletr qismiga tegishli bo‘lgan bir to‘g‘ri chiziqda joylashgan zaryadlar sistemasini muntazam ko‘pburchak shaklga keltirishda bajargan ishini hisoblashga oid misollar keltirilgan. Umumiy holda zaryadlar sistemasi turli xil qiymatli zaryadga ega bo‘lsa va ular orasidagi masofa turlicha bo‘lsa bu masalani yechish ancha murakkab bo‘ladi. Shuning uchun biz bir-biridan bir xil masofada joylashgan va bir to‘g‘ri chiziqda yotgan, biroq turlicha zaryadlarga bo‘lgan zaryadlar sistemasini muntazam ko‘pburchaklar shakliga olib kelish uchun bajariladigan ishni hisoblash masalasini ko‘rib chiqamiz.

Elektrostatik maydon bajaradigan ishi [1] quyidagicha aniqlanadi:

$$A=W_{p2}-W_{p1}, \quad (1)$$

bunda, W_{p1} va W_{p2} – zaryadlar sistemasining boshlang‘ich va ko‘chirilgandan keyingi potensial energiyalari. Soddalik uchun p indesni tushirib qoldiramiz.

Elektrostatik maydon bajargan ishi topish uchun nuqtaviy zaryadlar sistemasining potensial energiyalarini [2] aniqlash lozim. q_1, q_2, ... , q_N nuqtaviy zaryadlar sistemasidan iborat sistemaning potensial energiyasi:

$$W_p=\frac{1}{2}\sum_{k=1}^{N} q_k\varphi_k, \quad (2)$$

bunda, q_k – k-chi nuqtaviy zaryad, φ_k – ushbu zaryad joylashgan nuqtada boshqa zaryadlar hosil qilinayotgan maydon potensiali. Endi masalalar ko‘rishga o‘tamiz.

1-masala. Zaryadlari q_1, q_2, q_3, q_4, q_5, q_6 bo‘lgan va 1-rasmda ko‘rsatilgandek joylashgan nuqtaviy zaryadlar bir-biridan a masofada va bir to‘g‘ri chiziqda joylashishgan. Zaryadlar shunday ko‘chirilganki, q_1 va q_2 zaryadlarning joylashishi o‘zgartirilmay, q_1 zaryad atrofiga q_3, va q_5 zaryadlar soat strelkasiga teskari yo‘nalishda, q_2 zaryad atrofiga q_4 va q_6 zaryadlar soat strelkasi yo‘nalishi bo‘ylab burib muntazam oltiburchak shakliga keltirilgan. Zaryadlarni bunday ko‘chirishda bajarilgan ishni toping.

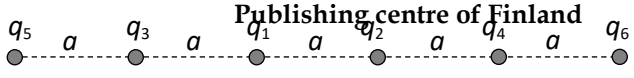
Berilgan:
q_1; q_2; q_3;
q_4; q_5; q_6;
a, $\alpha=120°$

Topish kerak
A=?

Zaryadlarni bir shakldan boshqa shaklga ko‘chirishda bajarilgan ishni (1) ifoda orqali topamiz. Buning uchun bu ifodaga kirgan potensial energiyalarni topish kerak.

Boshlang‘ich holatdagi potensial energiyani topish uchun

(2) ifodani 1-rasmdagi holatga qo‘llaymiz:



1-rasm

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$$W_1=q_1\varphi_2+q_1\varphi_3+q_1\varphi_4+q_1\varphi_5+q_1\varphi_6+q_2\varphi_3+q_2\varphi_4+q_2\varphi_5+$$
$$+q_2\varphi_6+q_3\varphi_4+q_3\varphi_5+q_3\varphi_6+q_4\varphi_5+q_4\varphi_6+q_5\varphi_6, \quad (3)$$

bu yerda, φ_i – i-indeksli zaryadning boshqa zaryadlar turgan nuqtalarda hosil qiluvchi potensial. Ushbu potensialning ifodasi quyidagicha [2]:

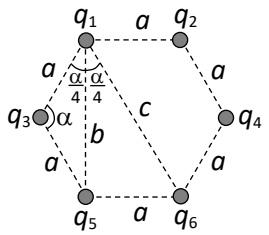
$$\varphi=\frac{1}{4\pi\varepsilon_o}\frac{q}{r}, \quad (4)$$

bu yerda, ε_o – elektr doimiysi, r – zaryadlar orasidagi masofa.

(4) ifodani (3) ifodaga qo‘yib quyidagini olamiz:

$$W_1=\frac{k}{a}\left(q_1q_2+q_1q_3+\frac{1}{2}q_1q_4+\frac{1}{2}q_1q_5+\frac{1}{3}q_1q_6+\frac{1}{2}q_2q_3+q_2q_4+\frac{1}{3}q_2q_5+\right.$$
$$\left.+\frac{1}{2}q_2q_6+\frac{1}{3}q_3q_4+q_3q_5+\frac{1}{4}q_3q_6+\frac{1}{4}q_4q_5+q_4q_6+\frac{1}{5}q_5q_6\right). \quad (5)$$

Endi 1-rasmda keltirilgan zaryadlarni masala shartiga ko‘ra muntazam oltiburchak shakliga keltiramiz (2-rasm). Muntazam oltiburchak uchun potensial energiya ifodasini yozamiz:



2-rasm

$$W_2=q_1\varphi_2'+q_1\varphi_3'+q_1\varphi_4'+q_1\varphi_5'+q_1\varphi_6'+q_2\varphi_3'+q_2\varphi_4'+q_2\varphi_5'+$$
$$+q_2\varphi_6'+q_3\varphi_4'+q_3\varphi_5'+q_3\varphi_6'+q_4\varphi_5'+q_4\varphi_6'+q_5\varphi_6'. \quad (6)$$

(4) ifodani (6) ifodaga qo‘ysak quyidagini olamiz:

$$W_2=\frac{k}{a}\left(q_1q_2+q_1q_3+q_2q_4+q_3q_5+q_4q_6+q_5q_6\right)+\frac{k}{b}\left(q_1q_4+q_1q_5+\right.$$
$$\left.+q_2q_3+q_2q_6+q_3q_6+q_4q_5\right)+\frac{k}{c}\left(q_1q_6+q_2q_5+q_3q_4\right), \quad (7)$$

bu yerda, α – muntazam oltiburchakning ichki burchagi, a – qo‘shni zaryadlar orasidagi masofa b va c masofalar esa sinuslar teoremasi yordamida topiladi:

$$b=a\frac{\sin\alpha}{\sin\alpha/4}, \quad c=a\frac{1}{\sin\alpha/4}. \quad (8)$$

(8) ifodani (7) ifodaga qo‘yamiz:

$$W_2=\frac{k}{a}\left[q_1q_2+q_1q_3+q_2q_4+q_3q_5+q_4q_6+q_5q_6+\frac{\sin\alpha/4}{\sin\alpha}\cdot\left(q_1q_4+q_1q_5+\right.\right.$$
$$\left.\left.+q_2q_3+q_2q_6+q_3q_6+q_4q_5\right)+\sin\alpha/4\cdot\left(q_1q_6+q_2q_5+q_3q_4\right)\right]. \quad (9)$$

Hosil bo‘lgan (9) va (5) ifodalarni (1) ifodaga qo‘yib zaryadlarni ko‘chirishda bajarilgan ishni topamiz:

$$A=\frac{k}{a}\left[\left(\frac{\sin\alpha/4}{\sin\alpha}-\frac{1}{2}\right)\cdot\left(q_1q_4+q_1q_5+q_2q_3+q_2q_6\right)+\left(\sin\alpha/4-\frac{1}{3}\right)\cdot\left(q_1q_6+\right.\right.$$

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$$+q_2q_5+q_3q_4)+\left(\frac{\sin\alpha/4}{\sin\alpha}-\frac{1}{4}\right)\cdot(q_3q_6+q_4q_5)+\frac{4}{5}q_5q_6\Bigg]. \qquad (10)$$

$\alpha=120°$ ekanligini hisobga olsak (10) ifoda quyidagiga keladi:

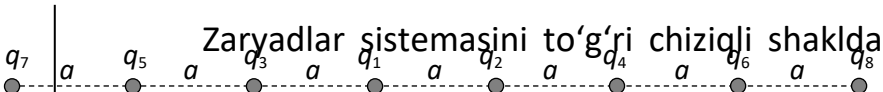
$$A=\frac{k}{a}\left[\frac{2\sqrt{3}-3}{6}\cdot(q_1q_4+q_1q_5+q_2q_3+q_2q_6)+\frac{1}{6}\cdot(q_1q_6+\right.$$

$$\left.+q_2q_5+q_3q_4)+\frac{4\sqrt{3}-3}{12}\cdot(q_3q_6+q_4q_5)+\frac{4}{5}q_5q_6\right].$$

Javob: $$A=\frac{k}{a}\left[\frac{2\sqrt{3}-3}{6}\cdot(q_1q_4+q_1q_5+q_2q_3+q_2q_6)+\frac{1}{6}\cdot(q_1q_6+\right.$$

$$\left.+q_2q_5+q_3q_4)+\frac{4\sqrt{3}-3}{12}\cdot(q_3q_6+q_4q_5)+\frac{4}{5}q_5q_6\right].$$

2-masala. q_1, q_2, q_3, q_4, q_5, q_6, q_7, q_8 zaryadlarga ega bo‘lgan va 3-rasmda ko‘rsatilgandek joylashgan nuqtaviy zaryadlar bir-biridan a masofada va bir to‘g‘ri chiziqda joylashishgan. Zaryadlar shunday ko‘chirilganki, q_1 va q_2 zaryadlarning joylashishi o‘zgartirilmay, q_1 zaryad atrofiga q_3, q_5 va q_7 zaryadlar soat strelkasiga teskari yo‘nalishda, q_2 zaryad atrofiga q_4, q_6 va q_8 zaryadlar soat strelkasi yo‘nalishi bo‘ylab burib muntazam sakkizburchak shakliga keltirilgan. Zaryadlarni ko‘chirishda bajarilgan ishini toping.



3-rasm

Berilgan:
q_1; q_2; q_3; q_4; q_5; q_6; q_7; q_8; a; $\alpha=135°$

Zaryadlar sistemasini to‘g‘ri chiziqli shakldan muntazam sakkizburchak shakliga keltirishda bajarilgan ishni (1) ifoda orqali topamiz. Avval bu isodaga kirgan potensial energiyani to‘g‘ri chiziqda joylashgan (3-rasm) hol uchun topib olamiz.

Topish kerak:

A=?

Buning uchun (2) ifodadan foydalanamiz:

$$W_1=q_1\varphi_2+q_1\varphi_3+q_1\varphi_4+q_1\varphi_5+q_1\varphi_6+q_1\varphi_7+q_1\varphi_8+q_2\varphi_3+q_2\varphi_4+q_2\varphi_5+$$
$$q_2\varphi_6+q_2\varphi_7+q_2\varphi_8+q_3\varphi_4+q_3\varphi_5+q_3\varphi_6+q_3\varphi_7+q_3\varphi_8+q_4\varphi_5+q_4\varphi_6+$$
$$q_4\varphi_7+q_4\varphi_8+q_5\varphi_6+q_5\varphi_7+q_5\varphi_8+q_6\varphi_7+q_6\varphi_8+q_7\varphi_8. \qquad (11)$$

Potensialning o‘rniga (4) ni qo‘yib potensial energiya uchun quyidagini olamiz:

$$W_1=\frac{k}{a}\left(q_1q_2+q_1q_3+\frac{1}{2}q_1q_4+\frac{1}{2}q_1q_5+\frac{1}{3}q_1q_6+\frac{1}{3}q_1q_7+\frac{1}{4}q_1q_8+\frac{1}{2}q_2q_3+\right.$$

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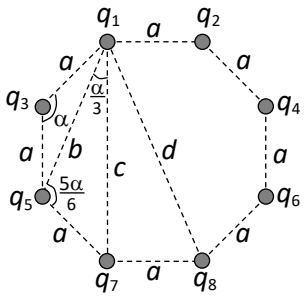
$$+q_2q_4+\frac{1}{3}q_2q_5+\frac{1}{2}q_2q_6+\frac{1}{4}q_2q_7+\frac{1}{3}q_2q_8+\frac{1}{3}q_3q_4+q_3q_5+\frac{1}{4}q_3q_6+$$
$$+\frac{1}{2}q_3q_7+\frac{1}{5}q_3q_8+\frac{1}{4}q_4q_5+q_4q_6+\frac{1}{5}q_4q_7+\frac{1}{2}q_4q_8+\frac{1}{5}q_5q_6+$$
$$+q_5q_7+\frac{1}{6}q_5q_8+\frac{1}{6}q_6q_7+q_6q_8+\frac{1}{7}q_7q_8). \qquad (12)$$



4-rasm

Endi birinchi holatda turgan zaryadlar sistemasini muntazam sakkizburchak shakliga keltiramiz (4-rasm). Hosil bo‘lgan sistema uchun potensial energiyaning ifodasini yozamiz:

$$W_1=q_1\varphi_2'+q_1\varphi_3'+q_1\varphi_4'+q_1\varphi_5'+q_1\varphi_6'+q_1\varphi_7'+q_1\varphi_8'+q_2\varphi_3'+q_2\varphi_4'+q_2\varphi_5'+$$
$$+q_2\varphi_6'+q_2\varphi_7'+q_2\varphi_8'+q_3\varphi_4'+q_3\varphi_5'+q_3\varphi_6'+q_3\varphi_7'+q_3\varphi_8'+q_4\varphi_5'+q_4\varphi_6'+$$
$$+q_4\varphi_7'+q_4\varphi_8'+q_5\varphi_6'+q_5\varphi_7'+q_5\varphi_8'+q_6\varphi_7'+q_6\varphi_8'+q_7\varphi_8' \qquad (13)$$

(4) ifodani (13) ifodaga qo‘ysak quyidagini olamiz:

$$W_2=\frac{k}{a}(q_1q_2+q_1q_3+q_2q_4+q_3q_5+q_4q_6+q_5q_7+q_6q_8+q_7q_8)+\frac{k}{b}(q_1q_4+q_1q_5+$$
$$+q_2q_3+q_2q_6+q_3q_7+q_4q_8+q_5q_8+q_6q_7)+\frac{k}{c}(q_1q_6+q_1q_7+q_2q_8+q_3q_4+$$
$$+q_3q_8+q_4q_7+q_5q_6)+\frac{k}{d}(q_1q_8+q_2q_7+q_3q_6+q_4q_5), \qquad (14)$$

bu yerda, α – muntazam sakkizburchakning ichki burchagi, a – qo‘shni zaryadlar orasidagi masofa b, c va d masofalar esa sinuslar teoremasi yordamida topiladi:

$$b=a\frac{\sin\alpha}{\sin\alpha/6},\quad c=a\frac{\sin5\alpha/6}{\sin\alpha/6},\quad d=a\frac{1}{\sin\alpha/6}. \qquad (15)$$

(15) ifodani (14) ifodaga qo‘yamiz:

$$W_2=\frac{k}{a}[q_1q_2+q_1q_3+q_2q_4+q_3q_5+q_4q_6+q_5q_7+q_6q_8+q_7q_8+\frac{\sin\alpha/6}{\sin\alpha}\cdot(q_1q_4+q_1q_5+$$
$$+q_2q_3+q_2q_6+q_3q_7+q_4q_8+q_5q_8+q_6q_7)+\frac{\sin\alpha/6}{\sin5\alpha/6}\cdot(q_1q_6+q_1q_7+q_2q_5+$$

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$+q_2q_8+q_3q_4+q_3q_8+q_4q_7+q_5q_6)+sin\alpha/6\cdot(q_1q_8+q_2q_7+q_3q_6+q_4q_5)]$. (16)

Hosil bo‘lgan (16) va (12) ifodalarni (1) ifodaga qo‘yib zaryadlarni ko‘chirishda bajarilgan ishni topamiz:

$$A=\frac{k}{a}[(1-\frac{1}{7})q_7q_8+\left(\frac{\sin\alpha/6}{\sin\alpha}-\frac{1}{2}\right)\cdot(q_1q_4+q_1q_5+q_2q_3+q_2q_6+q_3q_7+q_4q_8)+$$
$$+\left(\frac{\sin\alpha/6}{\sin\alpha}-\frac{1}{6}\right)\cdot(q_5q_4+q_6q_7)+\left(\frac{\sin\alpha/6}{\sin5\alpha/6}-\frac{1}{3}\right)\cdot(q_1q_6+q_1q_7+q_2q_5++q_2q_8+q_3q_4)+$$
$$+\left(\frac{\sin\alpha/6}{\sin5\alpha/6}-\frac{1}{5}\right)\cdot(q_3q_8+q_4q_7+q_5q_6)+(sin\alpha/6-\frac{1}{4})\cdot(q_1q_8+q_2q_7+q_3q_6+q_4q_5)]. \quad (17)$$

α=135° ekanligini hisobga olsak (17) ifoda quyidagiga keladi:

$$A=\frac{k}{a}[\frac{6}{7}q_7q_8+\frac{\sqrt{4-2\sqrt{2}}-1}{2}\cdot(q_1q_4+q_1q_5+q_2q_3+q_2q_6+q_3q_7+q_4q_8)+$$
$$+\frac{3\sqrt{4-2\sqrt{2}}-1}{6}\cdot(q_5q_4+q_6q_7)+\frac{3\sqrt{2}-4}{3}\cdot(q_1q_6+q_1q_7+q_2q_5++q_2q_8+q_3q_4)+$$
$$+\frac{5\sqrt{2}-6}{5}\cdot(q_3q_8+q_4q_7+q_5q_6)+\frac{2\sqrt{2-\sqrt{2}}-1}{4}\cdot(q_1q_8+q_2q_7+q_3q_6+q_4q_5)].$$

Javob: $$A=\frac{k}{a}[\frac{6}{7}q_7q_8+\frac{\sqrt{4-2\sqrt{2}}-1}{2}\cdot(q_1q_4+q_1q_5+q_2q_3+q_2q_6+q_3q_7+q_4q_8)+$$
$$+\frac{3\sqrt{4-2\sqrt{2}}-1}{6}\cdot(q_5q_4+q_6q_7)+\frac{3\sqrt{2}-4}{3}\cdot(q_1q_6+q_1q_7+q_2q_5++q_2q_8+q_3q_4)+$$
$$+\frac{5\sqrt{2}-6}{5}\cdot(q_3q_8+q_4q_7+q_5q_6)+\frac{2\sqrt{2-\sqrt{2}}-1}{4}\cdot(q_1q_8+q_2q_7+q_3q_6+q_4q_5)].$$

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