CHAPTER 21

1. $I = 30.0\,\mu A = 3\cdot 10^{-5} A$

$\Delta t = 40\,s$

$\Delta Q = I \Delta t = 1.2\cdot 10^{-3} C$

Number of electrons $= \frac{\Delta Q}{e} = \underline{7.5\cdot 10^{15}}$

5. $A = 4\cdot 10^{-6} m^2$

$I = 5 A$

$\rho = 2.7\ g/cm^3 = 2.7\cdot 10^6\ g/m^3$

Molar mass $= 24\ g/mol$

Mass of one atom $= \frac{\text{Molar mass}}{N_A}$

Number density of atoms $= \frac{\rho}{\text{mass of one atom}} =$

$= \frac{\rho}{\text{Molar mass}} \cdot N_A = 6.02\cdot 10^{28}\ m^{-3}$

One electron per atom, so

$n = 6.02\cdot 10^{28}\ m^{-3}$

$I = n e v_d A$

$v_d = \frac{I}{n e A} = \underline{1.3 \cdot 10^{-4} m/s}$

6. $R = 240 \Omega$

$\Delta V = 120 V$

$I = \frac{\Delta V}{R} = \underline{0.5 A}$

7. $\Delta V = 0.9 V$

$l = 1.5 m$

$A = 0.6 mm^2 = 0.6 \cdot 10^{-6} m^2$

$\rho = 5.6 \cdot 10^{-8} \Omega \cdot m$ (Table 21.1, page 689)

$R = \frac{\rho l}{A} = 0.14 \Omega$

$I = \frac{\Delta V}{R} = \underline{6.43 A}$

8. $m = 1 g = 10^{-3} kg$

$R = 0.5 \Omega$

density $= 8.92 \cdot 10^3 kg/m^3$

$\rho = 1.7 \cdot 10^{-8} \Omega m$

$m = \text{density} \cdot \text{volume} = \text{density} \cdot A \cdot \ell$ (1)

$R = \dfrac{\rho \ell}{A}$ (2)

<u>a)</u> multiply (1) and (2):

$mR = \text{density} \cdot A \cdot \ell \cdot \dfrac{\rho \ell}{A} = \text{density} \cdot \rho \ell^2$

$\ell = \sqrt{\dfrac{mR}{\text{density} \cdot \rho}} = \underline{1.82\ m}$

<u>(b)</u> From (1):

$A = \dfrac{m}{\text{density} \cdot \ell} = 6.17 \cdot 10^{-8}\ m^2 = \pi r^2$

$r = 1.4 \cdot 10^{-4}\ m$

$\text{diameter} = 2r = \underline{2.8 \cdot 10^{-4}\ m}$

<u>9 (a)</u> $\rho_0 = 2.82 \cdot 10^{-8}\ \Omega \cdot m$ at $T_0 = 20°C$

$T = 50°C$, $\alpha = 3.9 \cdot 10^{-3}\ (°C)^{-1}$

$\rho = \rho_0 (1 + \alpha (T - T_0)) = \underline{3.15 \cdot 10^{-8}\ \Omega \cdot m}$

<u>(b)</u> $E = 0.2\ V/m$

$J = \dfrac{E}{\rho} = \underline{6.35 \cdot 10^{6}\ A/m^2}$

(c) $d = 0.1\,mm$

$$r = \frac{d}{2} = 0.05\,mm = 5 \cdot 10^{-5}\,m$$

$$A = \pi r^2 = 7.85 \cdot 10^{-9}\,m^2$$

$$I = JA = 49.9 \cdot 10^{-3}\,A$$

(d) density $= 2.7 \cdot 10^6\,g/m^3$

Molar mass $= 27\,g/mol$

$$\text{Mass of one atom} = \frac{\text{Molar mass}}{N_A}$$

$$\text{Number density of atoms} = \frac{\text{density}}{\text{mass of one atom}} =$$

$$= \frac{\text{density}}{\text{molar mass}} \cdot N_A = 6.02 \cdot 10^{28}\,m^{-3}$$

One electron per atom, so

$$n = 6.02 \cdot 10^{28}\,m^{-3}$$

$$J = n e V_d$$

$$V_d = \frac{J}{ne} = 6.59 \cdot 10^{-3}\,m/s$$

(e) $l = 2\,m$

$$\Delta V = E \cdot l = 0.4\,V$$

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$T_1 = 58°C$ (Death Valley)

$I_1 = 1A$

$T_2 = -88°C$ (Antarctica)

$\alpha = 3{,}9 \cdot 10^{-3}\ (°C)^{-1}$

$R_1 = R_0(1+\alpha(T_1 - T_0))$ $\qquad T_0 = 20°C$

$R_2 = R_0(1+\alpha(T_2 - T_0))$

$\Delta V_1 = \Delta V_2$ so

$I_1 R_1 = I_2 R_2$

$$I_2 = I_1 \frac{R_1}{R_2} = I_1 \frac{R_0(1+\alpha(T_1-T_0))}{R_0(1+\alpha(T_2-T_0))} =$$

$$= 1A \cdot \frac{1{,}15}{0{,}58} = \underline{2A}$$

12 (a) Charge carrier density is a property of the material, so it <u>does not change.</u>

(b) $J = \frac{I}{A}$, A does not change, I doubles, so J <u>doubles</u>.

(c) $J = n e V_d$

$V_d = \frac{J}{ne}$ <u>doubles</u>

(d) $\rho = \frac{m_e}{ne^2\tau}$

$\tau = \frac{m_e}{ne^2\rho}$ <u>does not change.</u>

14 $P = 600W$

$\Delta V = 120V$

$P = \Delta V \cdot I$

$I = \frac{P}{\Delta V} = \underline{5A}$

$R = \frac{\Delta V}{I} = \underline{24\Omega}$

17 $\Delta V' = 140V$

$\Delta V = 120V$

$R' = R$

$P = \frac{(\Delta V)^2}{R}$

$\frac{P'}{P} = \frac{(\Delta V')^2/R}{(\Delta V)^2/R} = \left(\frac{\Delta V'}{\Delta V}\right)^2 = 1.36$

$P' - P = 0.36 P$

$$\frac{P' - P}{P} \cdot 100\% = \underline{36\%}$$

18. $P_1 = 11W$

$P_2 = 40W$

$t = 100h$

$cost = \$\, 0{,}08 / kW \cdot h = \$ 8 \cdot 10^{-5} / Wh$

energy difference $= (P_2 - P_1) \cdot t = 29 \cdot 10^2 Wh$

money saved $= 29 \cdot 10^2 Wh \cdot \$ 8 \cdot 10^{-5} / Wh =$

$= \underline{\$\, 0{,}232}$

19. $\Delta V = 120V$

$T_i = 20°C$

$I_i = 1{,}8\, A$

$I_f = 1{,}53 A$

(a) $P_f = \Delta V \cdot I_f = 184W$

(b) $R_i = \frac{\Delta V}{I_i}$

also $R_i = R_0 (1 + \alpha (T_i - T_0)) = R_0$

since $T_i = T_0 = 20° C$

$$R_f = \frac{\Delta V}{I_f} = R_0(1+\alpha(T_f - T_0)) = \frac{\Delta V}{I_i}(1+\alpha(T_f - T_0))$$

$$1+\alpha(T_f - T_0) = \frac{I_i}{I_f} = 1.18$$

$$\alpha(T_f - T_0) = 0.18$$

$$T_f - T_0 = \frac{0.18}{\alpha} = \frac{0.18}{0.4\cdot 10^{-3}(°C)^{-1}} = 441\ °C$$

$$T_f = T_0 + 441°C = \underline{461°C}$$

21 cost $= \$0.12/kWh = \$0.12\cdot 10^{-3}/Wh$

(a) $P = 40W$

$t = 2\text{ weeks} = 2\cdot 7\cdot 24h = 336h$

money $=$ cost $\cdot\, Pt = \underline{\$1.61}$

(b) $P = 970W$

$t = 3\,min = 0.05h$

money $=$ cost $\cdot\, Pt = \underline{\$5.82\cdot 10^{-3}}$

(c) $P = 5200W$

$t = 40\,min = 0.67h$

money $=$ cost $\cdot\, Pt = \underline{\$0.416}$

23 $\Delta V = 12\,V$

$E = 2\cdot 10^7\,J$

(a) $P = 8\,kW = 8\cdot 10^3\,W$

$P = \Delta V \cdot I$

$I = \frac{P}{\Delta V} = \underline{667\,A}$

(b) $v = 20\,m/s$

$t = \frac{E}{P} = 2500\,s$

$d = vt = 5\cdot 10^4\,m = \underline{50\,km}$

49 $P_1 = 25\,W$

$P_2 = 100\,W$

$\Delta V = 120\,V$

(a) $P = \frac{(\Delta V)^2}{R}$

$R = \frac{(\Delta V)^2}{P}$

$\underline{R_1 = 576\,\Omega}$ $\underline{R_2 = 144\,\Omega}$

(b) $P_1 = \Delta V \cdot I_1$

$I_1 = \frac{P_1}{\Delta V} = 0{,}21\,A = \frac{Q}{\Delta t}$

$\Delta t = \frac{Q}{0.21 A} = \frac{1 C}{0.21 A} = \underline{4.8 s}$

The charge does not change, its potential energy does.

(c) $\Delta t = \frac{1 J}{P_1} = \underline{0.04 s}$

The energy enters as the potential energy of the charges, exits as heat and light.

(d) $cost = \$0.07/kW \cdot h = \$0.07 \cdot 10^{-3}/Wh =$

$= \$0.07 \cdot 10^{-3} / W \cdot 3600 s = \$1.94 \cdot 10^{-8}/J$

The company sells energy with the cost of $\underline{\$1.94 \cdot 10^{-8}}$ per Joule.

$t = 30 \text{ days} = 30 \cdot 24 \cdot 3600 s = 2.6 \cdot 10^6 s$

$money = cost \cdot Pt = \underline{\$1.26}$

53 $P_1 = 1500W$

$P_2 = 750W$

$P_3 = 1000W$

$\Delta V = 120V$

(a) $P = \Delta V \cdot I$

$$I = \frac{P}{\Delta V}$$

$I_1 = 12.5A$

$I_2 = 6.25A$

$I_3 = 8.33A$

(b) $I_1 + I_2 + I_3 = 27.1A > 25A$

so it is not sufficient.

55 Batteries in series:

$\Delta V = 4 \cdot 1.5V = 6V$

$Q = 240C$

$R = 200\Omega$

$$I = \frac{\Delta V}{R} = 0.03A$$

$$\Delta t = \frac{Q}{I} = 8000s$$

26 Batteries in series:

$\Delta V = 2 \cdot 1{,}5\,V = 3V$

$R_1 = 0{,}255\,\Omega$

$R_2 = 0{,}153\,\Omega$

$I = 600\,mA = 0{,}6\,A$

(a) $R_{total} = \dfrac{\Delta V}{I} = 5\,\Omega = R_1 + R_2 + R_{lamp}$

$R_{lamp} = \underline{4{,}592\,\Omega}$

(b) $P = I \cdot R^2$

$P_{internal} = I^2 (R_1 + R_2)$

$P_{total} = I^2 R_{total}$

$\dfrac{P_{internal}}{P_{total}} = \dfrac{\cancel{I^2}(R_1 + R_2)}{\cancel{I^2} R_{total}} = \left(\dfrac{R_1 + R_2}{R_{total}}\right) = \underline{0{,}0816}$

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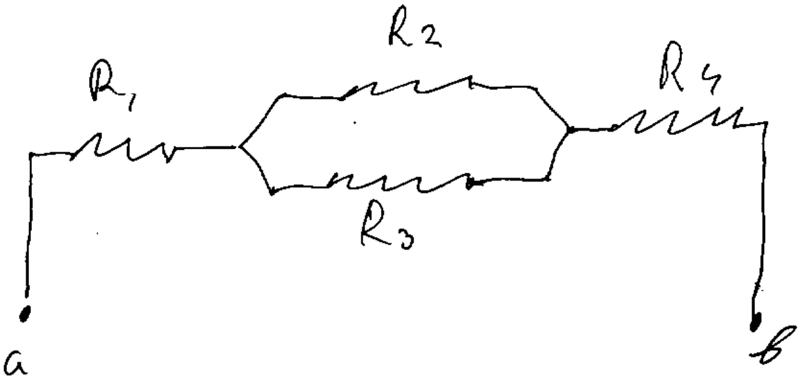

$R_1 = 4\,\Omega$

$R_2 = 7\,\Omega$

$R_3 = 10\,\Omega$

$R_4 = 9\,\Omega$

(a) 2 and 3 in parallel:

$$\frac{1}{R_{23}} = \frac{1}{R_2} + \frac{1}{R_3}$$

$$R_{23} = \frac{R_2 \cdot R_3}{R_2 + R_3} = 4.12\ \Omega$$

1, 23, 4 in series

$$R_{total} = R_1 + R_{23} + R_4 = \underline{17.12\ \Omega}$$

(b) $\Delta V = 34\ V$

$$I_{total} = \frac{\Delta V}{R_{total}} = 2\ A$$

1, 23, 4 in series so

$$\underline{I_1 = I_4} = I_{23} = I_{total} = \underline{2\ A}$$

$$\Delta V_{23} = I_{23} \cdot R_{23} = 8.18\ V = \Delta V_2 = \Delta V_3$$

$$I_2 = \frac{\Delta V_2}{R_2} = \underline{1.17\ A}$$

$$I_3 = \frac{\Delta V_3}{R_3} = \underline{0.818\ A}$$

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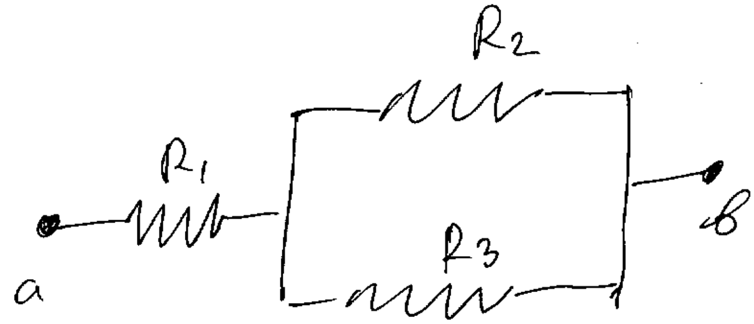

$$R = R_1 = R_2 = R_3 = 100\,\Omega$$

$$R_{23} = \frac{R_2 \cdot R_3}{R_2 + R_3} = \frac{R^2}{2R} = \frac{R}{2} \quad \text{(parallel)}$$

$$R_{total} = R_1 + R_{23} = \frac{3R}{2} \quad \text{(series)}$$

$$I_{total} = \frac{\Delta V}{R_{total}} = \frac{2}{3}\frac{\Delta V}{R} = I_1 = I_{23}$$

$$\Delta V_{23} = I_{23} \cdot R_{23} = \frac{1}{3}\Delta V = \Delta V_2 = \Delta V_3$$

$$I_2 = \frac{\Delta V_2}{R_2} = \frac{1}{3}\frac{\Delta V}{R}$$

$$I_3 = \frac{\Delta V_3}{R_3} = \frac{1}{3}\frac{\Delta V}{R}$$

$$P_1 = I_1^2 \cdot R_1 = \frac{4}{9}\frac{(\Delta V)^2}{R}$$

$$P_2 = I_2^2 \cdot R_2 = \frac{1}{9}\frac{(\Delta V)^2}{R}$$

$$P_3 = I_3^2 \cdot R_3 = \frac{1}{9}\frac{(\Delta V)^2}{R}$$

(a) Biggest power is delivered to R_1 which cannot exceed 25W so

$$25W = \frac{4}{9}\frac{(\Delta V_{max})^2}{R}$$

$$\Delta V_{max} = 75V$$

(b) $\Delta V = \Delta V_{max}$

$P_1 = 25W$

$$P_2 = P_3 = \frac{1}{9}\frac{(\Delta V)^2}{R} = \frac{P_1}{4} = 6.25W$$

$$P_{total} = P_1 + P_2 + P_3 = 37.5W$$

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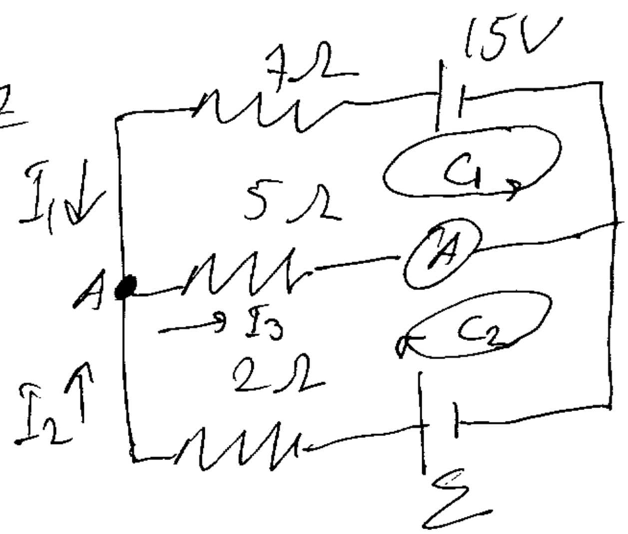

$I_3 = 2A$

consider loop C_1:

$$15V - 7\Omega \cdot I_1 - 5\Omega \cdot I_3 = 0$$

$$15V - 7\Omega \cdot I_1 - 10V = 0$$

$7\Omega \cdot I_1 = 5V$

$\underline{I_1 \simeq 0{,}714\,A}$

consider junction A:

$I_1 + I_2 = I_3$

$\underline{I_2} = I_3 - I_1 \simeq \underline{1{,}286\,A}$

consider loop C_2

$\mathcal{E} - I_2 \cdot 2\Omega - I_3 \cdot 5\Omega = 0$

$\underline{\mathcal{E}} = I_2 \cdot 2\Omega + I_3 \cdot 5\Omega = \underline{12{,}57V}$

4) $R = 1M\Omega = 10^6\Omega$

$C = 5\mu F = 5 \cdot 10^{-6} F$

$\mathcal{E} = 30V$

(a) $\tau = RC = \underline{5s}$

(b) $Q = C\mathcal{E} = \underline{1{,}5 \cdot 10^{-4} C}$

(c) $I(t) = \frac{\mathcal{E}}{R} e^{-t/\tau} = \frac{30}{10^6} A e^{-\frac{10s}{5s}} = \underline{4{,}06 \cdot 10^{-6} A}$

42 $C = 2nF = 2 \cdot 10^{-9} F$

$Q_0 = 5.1 \mu C = 5.1 \cdot 10^{-6} C$

$R = 1.3 k\Omega = 1.3 \cdot 10^{3} \Omega$

(a) $t = 9 \mu s = 9 \cdot 10^{-6} s$

$\tau = RC = 2.6 \cdot 10^{-6} s$

$I(t) = -I_0 e^{-t/\tau}$

$I_0 = \frac{\Delta V_0}{R} = \frac{Q_0/C}{R} = \frac{Q_0}{RC}$

$I(t) = -\frac{5.1 \cdot 10^{-6}}{2.6 \cdot 10^{-6}} A e^{-\frac{9 \cdot 10^{-6} s}{2.6 \cdot 10^{-6} s}} = -6.16 \cdot 10^{-2} A$

(b) $t = 8 \mu s = 8 \cdot 10^{-6} s$

$q(t) = Q_0 e^{-t/\tau} = 5.1 \cdot 10^{-6} C e^{-\frac{8 \cdot 10^{-6} s}{2.6 \cdot 10^{-6} s}} = 2.35 \cdot 10^{-7} C$

(c) $I_{max} = I_0 = \frac{Q_0}{RC} = 1.96 A$

since the current decreases with time,

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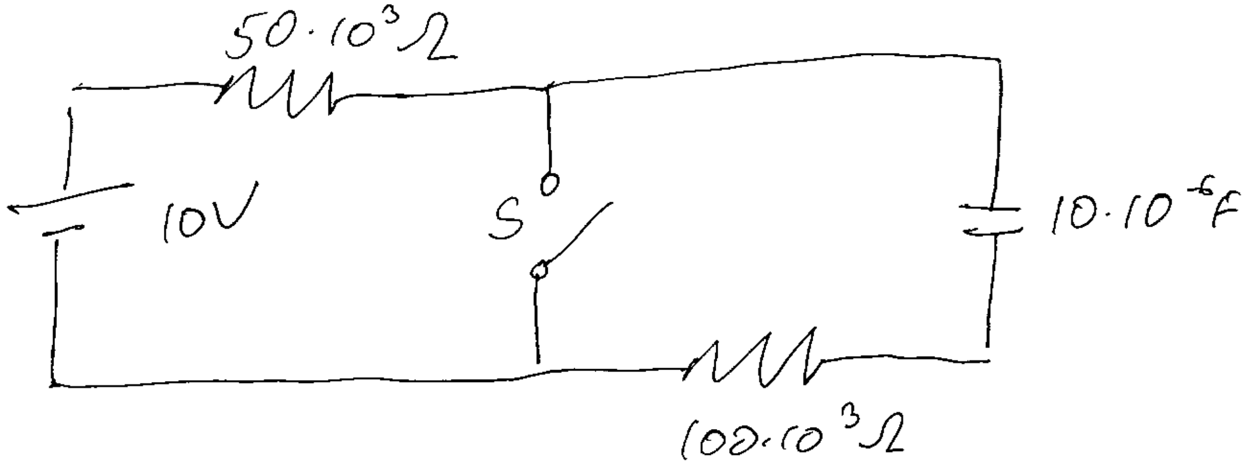
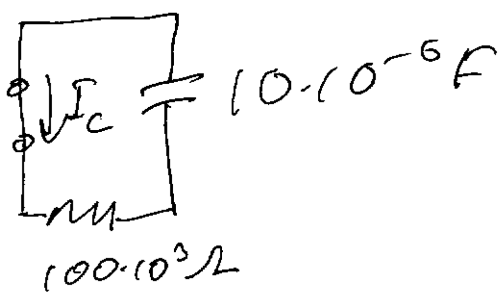


(a) Before the switch is closed

$R = R_1 + R_2 = 150 \cdot 10^3 \Omega$

$\tau = RC = 1.5\,s$

(b) After the switch is closed the capacitor discharges through the circuit



so $\tau = R_2 C = 1s$

(c) Before the switch is closed the capacitor has charge

$Q_0 = \Delta V \cdot C$

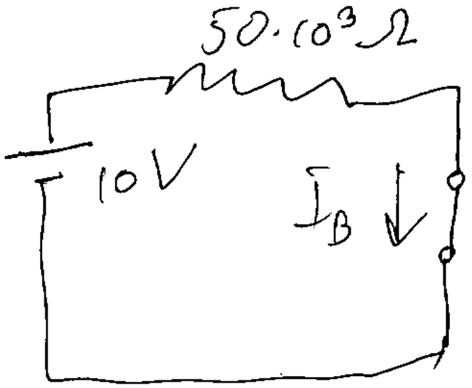
so as the capacitor begins to discharge

$I_c(t) = I_0 e^{-t/\tau}$

where $I_0 = \frac{Q_0}{R_2 C} = \frac{\Delta V \not{C}}{R_2 \not{C}} = 10^{-4} A$

$\tau = R_2 C = 1s$

But there is also another current through the switch from the other part of the circuit:



$I_B = \frac{\Delta V}{R_1} = 2 \cdot 10^{-4} A$

so the total current is

$I(t) = I_B + I_c(t) = \underline{2 \cdot 10^{-4} A + 1 \cdot 10^{-4} A \cdot e^{-t/1s}}$

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$C = 10\,\mu F = 10^{-5} F$

$\Delta V_0 = 10V$

$\Delta V(3s) = 4V$

$\Delta V(t) = \Delta V_0 (1 - e^{-t/\tau})$

$4V = 10V(1 - e^{-3s/\tau})$

$1 - e^{-3s/\tau} = 0{,}4$

$e^{-3s/\tau} = 0{,}6$

$\frac{3s}{\tau} = 0{,}511$

$\tau = 5.87s = RC$

$R = \underline{5.87 \cdot 10^5 \Omega}$

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$J = 6 \cdot 10^{-13} A/m^2$

$E = 100 V/m$

$J = \frac{E}{\rho} = \sigma E$

$\sigma = \frac{J}{E} = \underline{6 \cdot 10^{-15} (\Omega m)^{-1}}$