10.52 A p-channel MOSFET has an oxide thickness of $t_{ox} = 20$ nm $= 200$ Å and a substrate doping of $N_d = 5 \times 10^{15}$ cm^{-3}. (*a*) Find the body-effect coefficient. (*b*) Determine the body-to-source voltage, V_{BS}, such that the shift in threshold voltage, ΔV_T, from the $V_{BS} = 0$ curve is $\Delta V_T = -0.22$ V.

From Tables B.4 & B.6, $n_i = 1.5\times10^{10}$ cm^{-3} & $\varepsilon_r = 11.7$ for silicon and $\varepsilon_r = 3.9$ for SiO_2 at 300 K.

a) Per (10.82), adapted to use N_d, the body coefficient (using MKS units) is

$$\gamma = \frac{\sqrt{2e\varepsilon_s N_d}}{C_{ox}} = \frac{\sqrt{2(1.602176634\times10^{-19})(11.7)8.8541878\times10^{-12}(5\times10^{21})}}{(3.9)8.8541878\times10^{-12}/20\times10^{-9}}$$

$$\Rightarrow \underline{\gamma = 0.23596 \text{ V}^{1/2}}.$$

b) Per (10.83), adapted for p-channel, we get $\Delta V_T = -\gamma\left[\sqrt{2\phi_{fn} + V_{BS}} - \sqrt{2\phi_{fn}}\right]$.

Per (10.7), $\phi_{fn} = V_t \ln\left(\frac{N_d}{n_i}\right) = 0.025852 \ln\left(\frac{5\times10^{15}}{1.5\times10^{10}}\right) \Rightarrow \phi_{fn} = 0.32875725$ V.

$$-0.22 = -0.23596\left[\sqrt{2(0.328757) + V_{BS}} - \sqrt{2(0.328757)}\right]$$

$$\frac{0.22}{0.23596} + \sqrt{2(0.328757)} = \sqrt{2(0.328757) + V_{BS}}$$

$$1.7432338 = \sqrt{2(0.328757) + V_{BS}}$$

$$3.038864 = 2(0.328757) + V_{BS}$$

$$\Rightarrow \underline{V_{BS} = 2.38135 \text{ V}}.$$