Q1(1):

Let θ be the angle of projection and v be the initial speed.

We have $v_x = v\cos\theta$ and $v_y = v\sin\theta$.

Solving $v\sin\theta t - \frac{1}{2}gt^2 = 0$, we have the time that the ball travelled after projection $t = \frac{2v\sin\theta}{g}$.

Therefore, the horizontal range=$v\cos\theta(\frac{2v\sin\theta}{g}) = \frac{v^2\sin 2\theta}{g}$, which is directly proportional to $\sin 2\theta$.

Therefore, the required ratio is $\sin 2\cdot 45° : \sin 2\cdot 30° = 1 : (\frac{\sqrt{3}}{2}) = \boxed{\frac{2}{\sqrt{3}}}$.

Q1(2):

By $C = \frac{\epsilon_r S}{d}$, we have $C \propto \frac{1}{d}$ for the action. Therefore, the capacitance after the action=$\frac{1}{3}C$.

As the internal energy of the capacitor is given by $U = \frac{1}{2}QV$, i.e. $U = \frac{Q^2}{2C}$, we have $\Delta U = \frac{Q^2}{2}\Delta\frac{1}{C}$.

As the only source for the change in internal energy is the work done from outside, we have $W = \Delta U = \frac{Q^2}{2}(\frac{3}{C} - \frac{1}{C}) = \boxed{\frac{Q^2}{C}}$.

Q1(3):

By $pV = nRT$, we have $(1 + 5\cdot 1)(1) = nR(17 + 273)$.

Let V' be the volume on the surface, we have $(1)V' = nR(27 + 273)$.

Combine the two equations, we have $V' = \frac{300}{290}\cdot 6 \approx \boxed{6.2\ cm^2}$.

Q1(4):

The general form of Doppler effect is given by $f' = \frac{V - v_{observer}}{V - v_{source}} f$.

Note the the speed of the train is $72 \cdot \frac{1000}{3600} = 20\ m/s$.

When the train approaches the crossing signal, the observer (the passenger in the train) is travelling in the opposite direction to the propagation of the sound wave. Therefore, we have $720 = \frac{340+20}{340} f$, i.e. $f = 680\ Hz$.

After the train passes the crossing signal, the observer is travelling in the same direction to the propagation of the sound wave. Therefore, we have

$f' = \frac{340-20}{340} \cdot 680 = \boxed{640\ Hz}$.

Q1(5):

The equation of the decay is given by ${}^{238}_{92}U \rightarrow {}^{4}_{2}\alpha + {}^{234}_{90}?$ (here the element symbol of the element with atomic number 90 is denoted as ?).

Initially, the nucleus is at rest. Therefore, by the conservation of momentum, we have $4v + 234V = 0$, i.e. $|v/V| = \frac{234}{4} = \boxed{58.5}$.

Q2:

(1): The electric field from the charge at A on D is in the direction $S45°E$ and that from the charge at D is in the direction $N45°E$. Therefore, the net electric field on D is in the direction E, i.e. $\boxed{A \rightarrow B}$.

(2): The magnitudes of the electric fields from the charge at A and that at B are the same, where both are $k \cdot \frac{q}{2a^2}$ N/C as the distances between the two charges and D are $\sqrt{2}a$ by Pythagoras' theorem.

Consider the vector sum of the two electric fields, we have the magnitude of the electric field at D=$2 \cdot \frac{kq}{2a^2} \cos 45° = \boxed{\dfrac{kq^2}{\sqrt{2}a^2}}$.

(3): The electric potential on D due to the charge on A=$\frac{kq}{\sqrt{2}a}$ and that due to the charge on B=$\frac{-kq}{\sqrt{2}a}$.

Therefore, we have $V_D = \frac{kq}{\sqrt{2}a} - \frac{kq}{\sqrt{2}a} = 0\ J/C$.

Similarly, $V_C = \frac{kq}{a} - \frac{kq}{a} = 0\ J/C$.

Therefore, we have $\boxed{V_C = V_D}$.

Note: In fact, the electric potential throughout the whole line is equal to 0 due to symmetry.

(4): Similar to (3), the electric potential on D=$\frac{kq}{\sqrt{2}a} + \frac{kq}{\sqrt{2}a} = \frac{\sqrt{2}kq}{a}$ J/C and that on C=$\frac{2kq}{a}$ J/C.

Therefore, the difference in electric potential=$\frac{2kq}{a} - \frac{\sqrt{2}kq}{a} = \frac{(2-\sqrt{2})kq}{a}$ J/C and the work done is equal to the difference in electric potential energy=$\boxed{\dfrac{(\sqrt{2}-2)kq^2}{a}}$ J.

Note: The answer is wrong unless the question is asking about the work done per unit charge.

(5): As calculated, the electric potential energy of the charge at D=$-\frac{\sqrt{2}kq^2}{a}\ J$.

Once the charge is moved to the point of infinity, the EPE becomes 0.

Therefore, by the conservation of energy: KE+EPE=KE+EPE, we have

$$\frac{1}{2}mv^2 - \frac{\sqrt{2}kq^2}{a} = 0$$

$$v = \boxed{\sqrt{\frac{2\sqrt{2}kq^2}{ma}}}$$

Q3:

(1): Considering the cosine ratio, the height of A relative to the top=$R_0 \cos\theta_0 \approx R_0 - \frac{1}{2}R_0\theta_0^2$.

Therefore, $h \approx R_0 - (R_0 - \frac{1}{2}R_0\theta_0^2) = \boxed{\frac{1}{2}R_0\theta_0^2}$.

(2): Set the GPE as 0 at the height of B.

Consider the conservation of energy: KE+GPE=KE+GPE, we have

$$\frac{1}{2}mv_{max}^2 + 0 = 0 + mgh$$

$$v_{max} = \boxed{\sqrt{2gh}}$$

(3): Note that θ_0 is in radian measure*. Therefore, by definition, we have $\widehat{AB} = R_0\theta_0$.

*: Otherwise, the approximations $\sin\theta_0 \approx \theta_0$ and $\cos\theta_0 \approx 1 - \frac{1}{2}\theta_0^2$ are not valid.

(4): Combine the results of (1)-(3), we have $\bar{t} = \frac{R_0\theta_0}{\sqrt{2g(\frac{1}{2}R_0\theta_0^2)}} = \boxed{\sqrt{\frac{R_0}{g}}}$.

(5): The period of a simple pendulum is given by $T = 2\pi\sqrt{\frac{L}{g}}$.

Therefore, $t = \frac{T}{4} = \frac{\pi}{2}\sqrt{\frac{R_0}{g}}$.

Hence, we have the ratio $\boxed{t/\bar{t} = \frac{\pi}{2}}$.

Q4:

(1): The total mass=$0.2 \cdot 16 \cdot 2 + 0.3 \cdot 14 \cdot 2 = \boxed{14.8\ g}$.

Note: Oxygen and nitrogen are diatomic molecules.

(2): As oxygen molecules are diatomic, we have $k = \frac{7}{5}$.

As given, we have $c_p = \frac{\frac{7}{5}}{\frac{7}{5}-1}R = \frac{7}{2}R$.

Therefore, the heat capacity of oxygen=$nc_p = 0.2 \cdot \frac{7}{2}R = \boxed{0.7R}$.

(3): Similar to (2), the heat capacity of nitrogen=$0.3 \cdot \frac{7}{2}R = 1.05R$.

Therefore, the total heat capacity of the container=$1.05R + 0.7R = \boxed{1.75R}$.

(4): Consider the internal energy, we have $U = \frac{3}{2}nkT = \frac{1}{2}mv^2$. Therefore, we have $v^2 \propto \frac{n}{m}$.

The higher the mole to mass ratio, the higher the speed of molecule.

As the ratio for oxygen=$\frac{0.2}{2\cdot 16} = \frac{1}{160}$ and that for nitrogen=$\frac{0.3}{2\cdot 14} = \frac{1}{\frac{280}{3}} > \frac{1}{160}$, we have $\boxed{v_1 < v_2}$.

Q5:

Background: Unlike standing waves on a string, standing water waves have antinodes at the end and nodes in the middle. Refer to this video for a visual insight: https://youtu.be/xhtg-RosQHw?si=vLaKGXeBx2y12rdm.

(1): As the frequency is fixed to minimum, the standing wave is of first harmonic. Therefore, there is $\boxed{1}$ node.

(2): There are $\boxed{2}$ nodes on the walls.

(3): As there is a $\frac{1}{2}$ wave between the two walls, the wave length is equal to twice the separation between walls, i.e. $\boxed{2L}$.