HESS' LAW 2

Find : $C(s) + \frac{1}{2}\,O_2(g) + N_2(g) + 2\,H_2(g) \longrightarrow CO(NH_2)_2(s)$ $\Delta H = ?$

This is the most important step in the entire process. Without a clear goal, Hess' Law does not work. The question asks you to find the heat of formation for urea. These means you need to write a formation reaction as shown above. There must be element reactants only and one more of one product only.

Find : $C(s) + \frac{1}{2}O_2(g) + N_2(g) + 2H_2(g) \longrightarrow CO(NH_2)_2(s)$ $\Delta H = ?$

Given :

(1) $2NH_3(g) + 3H_2O(l) \longrightarrow NH_4NO_3(s) + 4H_2(g)$ $\Delta H = +583.6$ kJ

(2) $CH_2O(l) \longrightarrow CO(g) + H_2(g)$ $\Delta H = -1.9$ kJ

(3) $CH_2O(l) + 2NH_3(g) \longrightarrow CO(NH_2)_2(s) + 2H_2(g)$ $\Delta H = -133.1$ kJ

Next step is to write out the obvious given equations and number them.

Find : $C(s) + \frac{1}{2}O_2(g) + N_2(g) + 2H_2(g) \longrightarrow CO(NH_2)_2(s)$ $\Delta H = ?$

Given :

(1)	$2NH_3(g) + 3H_2O(l) \longrightarrow NH_4NO_3(s) + 4H_2(g)$	$\Delta H = +583.6$ kJ
(2)	$CH_2O(l) \longrightarrow CO(g) + H_2(g)$	$\Delta H = -1.9$ kJ
(3)	$CH_2O(l) + 2NH_3(g) \longrightarrow CO(NH_2)_2(s) + 2H_2(g)$	$\Delta H = -133.1$ kJ
(4)	$C(s) + \frac{1}{2}O_2(g) \longrightarrow CO(g)$	$\Delta H = -110.5$ kJ
(5)	$H_2(g) + \frac{1}{2}O_2(g) \longrightarrow H_2O(l)$	$\Delta H = -285.8$ kJ
(6)	$N_2(g) + 2H_2(g) + \frac{3}{2}O_2(g) \longrightarrow NH_4NO_3(s)$	$\Delta H = -583.6$ kJ

Further decoding the question, requires writing out three more formation reactions. In this question, the heats of formation for these three reactions are given in the question. You will frequently need to look these up in a table of heats of formation.

Find : $C(s) + \frac{1}{2}\,O_2(g) + N_2(g) + 2\,H_2(g) \longrightarrow CO(NH_2)_2(s)$ $\Delta H = ?$

Given :

(1) $2\,NH_3(g) + 3\,H_2O(l) \longrightarrow NH_4NO_3(s) + 4\,H_2(g)$ $\Delta H = +\ 583.6\ kJ$

(2) $CH_2O(l) \longrightarrow CO(g) + H_2(g)$ $\Delta H = -\ 1.9\ kJ$

(3) $CH_2O(l) + 2\,NH_3(g) \longrightarrow CO(NH_2)_2(s) + 2\,H_2(g)$ $\Delta H = -\ 133.1\ kJ$

(4) $C(s) + \frac{1}{2}\,O_2(g) \longrightarrow CO(g)$ $\Delta H = -\ 110.5\ kJ$

(5) $H_2(g) + \frac{1}{2}\,O_2(g) \longrightarrow H_2O(l)$ $\Delta H = -\ 285.8\ kJ$

(6) $N_2(g) + 2\,H_2(g) + \frac{3}{2}\,O_2(g) \longrightarrow NH_4NO_3(s)$ $\Delta H = -\ 583.6\ kJ$

---

(3) $CH_2O(l) + 2\,NH_3(g) \longrightarrow CO(NH_2)_2(s) + 2\,H_2(g)$ $\Delta H = -\ 133.1\ kJ$

Welcome to the game! My suggestion is to pick the most complex formula that is present in your find line as a starting point. It turns out that the formula for urea shows up only in equation (3) and is on the side of the equation that you want. Therefore use this equation as is. Like solving systems of linear equations in math, once you have used this equation correctly, there will be no need to use it again.

Using this equation the way it is, introduces two formula you do not want plus one formula you do want, but on the wrong side of the equation. Hence the game!!

Find : $C(s) + \frac{1}{2}O_2(g) + N_2(g) + 2\,H_2(g) \longrightarrow CO(NH_2)_2(s)$ ΔH= ?

Given :

(1) $2\,NH_3(g) + 3\,H_2O(l) \longrightarrow NH_4NO_3(s) + 4\,H_2(g)$ ΔH= + 583.6 kJ

(2) $CH_2O(l) \longrightarrow CO(g) + H_2(g)$ ΔH= − 1.9 kJ

(3) $CH_2O(l) + 2\,NH_3(g) \longrightarrow CO(NH_2)_2(s) + 2\,H_2(g)$ ΔH= − 133.1 kJ

(4) $C(s) + \frac{1}{2}O_2(g) \longrightarrow CO(g)$ ΔH= − 110.5 kJ

(5) $H_2(g) + \frac{1}{2}O_2(g) \longrightarrow H_2O(l)$ ΔH= − 285.8 kJ

(6) $N_2(g) + 2\,H_2(g) + \frac{3}{2}O_2(g) \longrightarrow NH_4NO_3(s)$ ΔH= − 583.6 kJ

---

(3) $CH_2O(l) + 2\,NH_3(g) \longrightarrow CO(NH_2)_2(s) + 2\,H_2(g)$ ΔH= − 133.1 kJ

rev (2) $CO(g) + H_2(g) \longrightarrow CH_2O(l)$ ΔH= + 1.9 kJ

There is more than one way to proceed here. I have chosen to eliminate formaldehyde here. Because this formula shows up on opposite side of the "equal" signs in equal molar amounts, it will cancel out as shown in red.

This step introduces CO, another substance you do not want. Don't worry about this, as it is a necessary step.

Find : $C(s) + \frac{1}{2} O_2(g) + N_2(g) + 2\,H_2(g) \longrightarrow CO(NH_2)_2(s)$ $\Delta H = ?$

Given :

(1)	$2\,NH_3(g) + 3\,H_2O(l) \longrightarrow NH_4NO_3(s) + 4\,H_2(g)$	$\Delta H = +\,583.6$ kJ
(2)	$CH_2O(l) \longrightarrow CO(g) + H_2(g)$	$\Delta H = -\;\;1.9$ kJ
(3)	$CH_2O(l) + 2\,NH_3(g) \longrightarrow CO(NH_2)_2(s) + 2\,H_2(g)$	$\Delta H = -\,133.1$ kJ
(4)	$C(s) + \frac{1}{2} O_2(g) \longrightarrow CO(g)$	$\Delta H = -\,110.5$ kJ
(5)	$H_2(g) + \frac{1}{2} O_2(g) \longrightarrow H_2O(l)$	$\Delta H = -\,285.8$ kJ
(6)	$N_2(g) + 2\,H_2(g) + \frac{3}{2} O_2(g) \longrightarrow NH_4NO_3(s)$	$\Delta H = -\,583.6$ kJ

(3)	$CH_2O(l) + 2\,NH_3(g) \longrightarrow CO(NH_2)_2(s) + 2\,H_2(g)$	$\Delta H = -\,133.1$ kJ
rev (2)	$CO(g) + H_2(g) \longrightarrow CH_2O(l)$	$\Delta H = +\;\;1.9$ kJ
rev (1)	$NH_4NO_3(s) + 4\,H_2(g) \longrightarrow 2\,NH_3(g) + 3\,H_2O(l)$	$\Delta H = -\,583.6$ kJ

I have gone after ammonia next, again introducing more formula that I do not want.

HESS' LAW 2

Find : $C(s) + \frac{1}{2}O_2(g) + N_2(g) + 2H_2(g) \longrightarrow CO(NH_2)_2(s)$ $\Delta H = ?$

Given :

(1)	$2NH_3(g) + 3H_2O(l) \longrightarrow NH_4NO_3(s) + 4H_2(g)$	$\Delta H = +583.6$ kJ
(2)	$CH_2O(l) \longrightarrow CO(g) + H_2(g)$	$\Delta H = -1.9$ kJ
(3)	$CH_2O(l) + 2NH_3(g) \longrightarrow CO(NH_2)_2(s) + 2H_2(g)$	$\Delta H = -133.1$ kJ
(4)	$C(s) + \frac{1}{2}O_2(g) \longrightarrow CO(g)$	$\Delta H = -110.5$ kJ
(5)	$H_2(g) + \frac{1}{2}O_2(g) \longrightarrow H_2O(l)$	$\Delta H = -285.8$ kJ
(6)	$N_2(g) + 2H_2(g) + \frac{3}{2}O_2(g) \longrightarrow NH_4NO_3(s)$	$\Delta H = -583.6$ kJ

---

(3)	$CH_2O(l) + 2NH_3(g) \longrightarrow CO(NH_2)_2(s) + 2H_2(g)$	$\Delta H = -133.1$ kJ
rev (2)	$CO(g) + H_2(g) \longrightarrow CH_2O(l)$	$\Delta H = +1.9$ kJ
rev (1)	$NH_4NO_3(s) + 4H_2(g) \longrightarrow 2NH_3(g) + 3H_2O(l)$	$\Delta H = -583.6$ kJ
(4)	$C(s) + \frac{1}{2}O_2(g) \longrightarrow CO(g)$	$\Delta H = -110.5$ kJ

Elimination of Carbon Monoxide.

HESS' LAW 2

Find : $C(s) + \frac{1}{2} O_2(g) + N_2(g) + 2\,H_2(g) \longrightarrow CO(NH_2)_2(s)$ $\Delta H = ?$

Given :

(1)	$2\,NH_3(g) + 3\,H_2O(l) \longrightarrow NH_4NO_3(s) + 4\,H_2(g)$	$\Delta H = +\,583.6$ kJ
(2)	$CH_2O(l) \longrightarrow CO(g) + H_2(g)$	$\Delta H = -\;\;1.9$ kJ
(3)	$CH_2O(l) + 2\,NH_3(g) \longrightarrow CO(NH_2)_2(s) + 2\,H_2(g)$	$\Delta H = -\,133.1$ kJ
(4)	$C(s) + \frac{1}{2} O_2(g) \longrightarrow CO(g)$	$\Delta H = -\,110.5$ kJ
(5)	$H_2(g) + \frac{1}{2} O_2(g) \longrightarrow H_2O(l)$	$\Delta H = -\,285.8$ kJ
(6)	$N_2(g) + 2\,H_2(g) + \frac{3}{2} O_2(g) \longrightarrow NH_4NO_3(s)$	$\Delta H = -\,583.6$ kJ

---

(3)	$CH_2O(l) + 2\,NH_3(g) \longrightarrow CO(NH_2)_2(s) + 2\,H_2(g)$	$\Delta H = -\,133.1$ kJ
rev (2)	$CO(g) + H_2(g) \longrightarrow CH_2O(l)$	$\Delta H = +\;\;1.9$ kJ
rev (1)	$NH_4NO_3(s) + 4\,H_2(g) \longrightarrow 2\,NH_3(g) + 3\,H_2O(l)$	$\Delta H = -\,583.6$ kJ
(4)	$C(s) + \frac{1}{2} O_2(g) \longrightarrow CO(g)$	$\Delta H = -\,110.5$ kJ
(6)	$N_2(g) + 2\,H_2(g) + \frac{3}{2} O_2(g) \longrightarrow NH_4NO_3(s)$	$\Delta H = -\,583.6$ kJ

`Elimination of ammonium nitrate.`

HESS' LAW 2

Find : $C(s) + \frac{1}{2}O_2(g) + N_2(g) + 2\,H_2(g) \longrightarrow CO(NH_2)_2(s)$ $\Delta H = ?$

Given :

(1)	$2\,NH_3(g) + 3\,H_2O(l) \longrightarrow NH_4NO_3(s) + 4\,H_2(g)$	$\Delta H = +\,583.6$ kJ
(2)	$CH_2O(l) \longrightarrow CO(g) + H_2(g)$	$\Delta H = -\,1.9$ kJ
(3)	$CH_2O(l) + 2\,NH_3(g) \longrightarrow CO(NH_2)_2(s) + 2\,H_2(g)$	$\Delta H = -\,133.1$ kJ
(4)	$C(s) + \frac{1}{2}O_2(g) \longrightarrow CO(g)$	$\Delta H = -\,110.5$ kJ
(5)	$H_2(g) + \frac{1}{2}O_2(g) \longrightarrow H_2O(l)$	$\Delta H = -\,285.8$ kJ
(6)	$N_2(g) + 2\,H_2(g) + \frac{3}{2}O_2(g) \longrightarrow NH_4NO_3(s)$	$\Delta H = -\,583.6$ kJ

---

(3)	$CH_2O(l) + 2\,NH_3(g) \longrightarrow CO(NH_2)_2(s) + 2\,H_2(g)$	$\Delta H = -\,133.1$ kJ
rev (2)	$CO(g) + H_2(g) \longrightarrow CH_2O(l)$	$\Delta H = +\,1.9$ kJ
rev (1)	$NH_4NO_3(s) + 4\,H_2(g) \longrightarrow 2\,NH_3(g) + 3\,H_2O(l)$	$\Delta H = -\,583.6$ kJ
(4)	$C(s) + \frac{1}{2}O_2(g) \longrightarrow CO(g)$	$\Delta H = -\,110.5$ kJ
(6)	$N_2(g) + 2\,H_2(g) + \frac{3}{2}O_2(g) \longrightarrow NH_4NO_3(s)$	$\Delta H = -\,583.6$ kJ
re 3 x (5)	$3\,H_2O(l) \longrightarrow 3\,H_2(g) + \frac{3}{2}O_2(g)$	$\Delta H = +\,857.4$ kJ

$$C(s) + \frac{1}{2}O_2(g) + N_2(g) + 2\,H_2(g) \longrightarrow CO(NH_2)_2(s)$$

This final equation is like a key in a lock. The goal behind 3 times the reverse of (5) was to cancel out water. As it turns out this also allows for the correct amount of both hydrogen and oxygen. The addition of hydrogen is simply 7 moles to the left cancels 5 moles to the right, leaving behind 2 moles on the left, exactly what is wanted. Oxygen is similar. On occasion, the fractional nature of this step may require some rough work to see if it works (using lowest common denominators and improper fractions works the best).

Please note that all of the uncancelled substances show up in the final answer line. Also note that this line must be identical to the "find" line!

HESS' LAW 2

Find :	$C(s) + \frac{1}{2}\,O_2(g) + N_2(g) + 2\,H_2(g) \longrightarrow CO(NH_2)_2(s)$	$\Delta H = ?$

Given :

(1)	$2\,NH_3(g) + 3\,H_2O(l) \longrightarrow NH_4NO_3(s) + 4\,H_2(g)$	$\Delta H = +\ 583.6$ kJ
(2)	$CH_2O(l) \longrightarrow CO(g) + H_2(g)$	$\Delta H = -\ 1.9$ kJ
(3)	$CH_2O(l) + 2\,NH_3(g) \longrightarrow CO(NH_2)_2(s) + 2\,H_2(g)$	$\Delta H = -\ 133.1$ kJ
(4)	$C(s) + \frac{1}{2}\,O_2(g) \longrightarrow CO(g)$	$\Delta H = -\ 110.5$ kJ
(5)	$H_2(g) + \frac{1}{2}\,O_2(g) \longrightarrow H_2O(l)$	$\Delta H = -\ 285.8$ kJ
(6)	$N_2(g) + 2\,H_2(g) + \frac{3}{2}\,O_2(g) \longrightarrow NH_4NO_3(s)$	$\Delta H = -\ 583.6$ kJ

---

(3)	$CH_2O(l) + 2\,NH_3(g) \longrightarrow CO(NH_2)_2(s) + 2\,H_2(g)$	$\Delta H = -\ 133.1$ kJ
rev (2)	$CO(g) + H_2(g) \longrightarrow CH_2O(l)$	$\Delta H = +\ 1.9$ kJ
rev (1)	$NH_4NO_3(s) + 4\,H_2(g) \longrightarrow 2\,NH_3(g) + 3\,H_2O(l)$	$\Delta H = -\ 583.6$ kJ
(4)	$C(s) + \frac{1}{2}\,O_2(g) \longrightarrow CO(g)$	$\Delta H = -\ 110.5$ kJ
(6)	$N_2(g) + 2\,H_2(g) + \frac{3}{2}\,O_2(g) \longrightarrow NH_4NO_3(s)$	$\Delta H = -\ 583.6$ kJ
re 3 x (5)	$3\,H_2O(l) \longrightarrow 3\,H_2(g) + \frac{3}{2}\,O_2(g)$	$\Delta H = +\ 857.4$ kJ

$C(s) + \frac{1}{2}\,O_2(g) + N_2(g) + 2\,H_2(g) \longrightarrow CO(NH_2)_2(s)$	$\Delta H = -\ 551.5$ kJ

Finally, the addition of the enthalpy values gives the answer!