The Element That Hid for 134 Years: Lanthanoid Contraction

Hafnium sat in zircon beside zirconium but was found only in 1923, 134 years after zirconium, because the two are almost the same size (Zr 160 pm, Hf 159 pm) despite Hf's 32 extra electrons and extra shell. Between them in period 6 sit the 14 lanthanoids, across which the size of atoms and Ln^{3+} ions decreases steadily (La^{3+} ≈ 103 pm → Lu^{3+} ≈ 86 pm): the lanthanoid contraction. Each step adds a proton while the new electron enters 4f, which shields poorly (s > p > d > f), so the outer electrons are pulled in. The contraction cancels the expected increase in period 6: Zr ≈ Hf, Nb ≈ Ta, Mo ≈ W; Zr and Hf (and the lanthanoids) are hard to separate; and the basicity of $Ln(OH)_3$ decreases from La to Lu.

Name: Date: Score: ____ / 24

A. Fill in the blanks

1. The steady decrease in size from La to Lu is called the ____.

2. Across the lanthanoids, the new electron enters the ____ subshell.

3. The metallic radius of Zr is 160 pm and that of Hf is ____ pm.

4. The Ln^{3+} ion with the largest radius is ____.

5. Hafnium was discovered in the year ____.

B. True or False

6. 4f electrons shield the outer electrons very effectively. True / False

7. Zr and Hf have almost the same atomic radius. True / False

8. The basicity of $Ln(OH)_3$ increases from La to Lu. True / False

9. Nb and Ta have nearly equal radii. True / False

10. The lanthanoid contraction makes Zr and Hf easy to separate. True / False

C. Assertion and reason

11. Assertion (A): Hf has nearly the same radius as Zr.
Reason (R): The lanthanoid contraction cancels the size increase expected from the extra shell.

(a) Both A and R are true, and R explains A
(b) Both A and R are true, but R does not explain A
(c) A is true, R is false
(d) A is false, R is true

Answer: _____

12. Assertion (A): Basicity of $Ln(OH)_3$ decreases from La to Lu.
Reason (R): The smaller Ln^{3+} holds OH^- more strongly, so the Ln–OH bond is more covalent.

(a) Both A and R are true, and R explains A
(b) Both A and R are true, but R does not explain A
(c) A is true, R is false
(d) A is false, R is true

Answer: _____

D. Choose the correct option

13. The lanthanoid contraction is caused by:

(a) poor shielding by 4f electrons
(b) addition of a new shell
(c) decrease in nuclear charge
(d) good shielding by 4f electrons

Answer: _____

14. Which pair has nearly identical radii?

(a) Zr and Hf
(b) Ti and Zr
(c) Sc and Y
(d) Cr and Mo

Answer: _____

15. The order of shielding effect is:

(a) s > p > d > f
(b) f > d > p > s
(c) d > f > s > p
(d) p > s > d > f

Answer: _____

16. The most basic hydroxide among these is:

(a) $La(OH)_3$
(b) $Gd(OH)_3$
(c) $Yb(OH)_3$
(d) $Lu(OH)_3$

Answer: _____

17. Reactor-grade zirconium must be almost free of:

(a) hafnium
(b) titanium
(c) uranium
(d) oxygen

Answer: _____

18. The number of elements between La and Hf is:

(a) 14
(b) 10
(c) 8
(d) 18

Answer: _____

E. Numerical problems

19. Ln^{3+} radius falls from 103 pm (La^{3+}) to 86 pm (Lu^{3+}). Find the total decrease.

20. Hf has Z = 72 and Zr has Z = 40. How many more electrons does Hf have?

F. Short answer questions

21. Define lanthanoid contraction and give its cause.

22. Give three consequences of the lanthanoid contraction.

23. Why must zirconium for nuclear reactors be purified from hafnium?

G. Match the columns

24. Match each item in Column A with the correct item in Column B.

Column A	Column B	Your answer
1. Zr / Hf	(a) 103 / 86 pm	1 → ____
2. La^{3+} / Lu^{3+}	(b) 160 / 159 pm	2 → ____

Detailed solutions

1. lanthanoid contraction

2. 4f

3. 159

4. La^{3+}

5. 1923

6. False. They shield poorly.

7. True. 160 and 159 pm.

8. False. It decreases.

9. True. Both about 146 pm.

10. False. It makes them very hard to separate.

11. (a) Zr 160, Hf 159 pm.

12. (a) $Lu(OH)_3$ least basic.

13. (a) poor shielding by 4f electrons. Effective nuclear charge rises.

14. (a) Zr and Hf. Lanthanoid contraction.

15. (a) s > p > d > f. f shields least.

16. (a) $La(OH)_3$. Largest Ln^{3+}.

17. (a) hafnium. Hf absorbs neutrons strongly.

18. (a) 14. Ce to Lu.

19. 103 − 86. **Answer: 17 pm**

20. 72 − 40. **Answer: 32**

21. The steady decrease in size of atoms and Ln^{3+} ions from La to Lu; each step adds +1 nuclear charge while the new 4f electron shields poorly, so the outer electrons are pulled in.

22. 4d and 5d elements of a group have nearly equal radii (Zr/Hf, Nb/Ta, Mo/W); Zr and Hf (and the lanthanoids) are hard to separate; basicity of $Ln(OH)_3$ decreases from La to Lu.

23. Zr hardly absorbs neutrons, but Hf absorbs thermal neutrons hundreds of times more strongly; Hf occurs with Zr because of their equal size, so it must be removed.

24. 1 → (b), 2 → (a).