## General Registers

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  | Usage |
| R0 |  | This register is always zero |  |
| R1 | acc | Accumulator | First parameter / return value |
| R2 | x | ‘x’ index register | Second parameter / Loop counter |
| R3 | y | ‘y’ index register | Third parameter |
| R4 |  |  |  |
| R5 |  |  |  |
| R6 |  |  |  |
| R7 |  |  |  |
| R8 |  |  |  |
| R9 |  |  |  |
| R10 |  |  |  |
| R11 |  |  |  |
| R12 |  |  |  |
| R13 |  |  |  |
| R14 |  |  |  |
| R15 |  |  |  |
|  |  |  |  |

## Special Purpose Registers

|  |  |  |  |
| --- | --- | --- | --- |
| Code |  |  |  |
| 0 | cc | Cache control register |  |
|  |  | Bit 0 = instruction cache enable | |
|  |  | Bit 1 = Data cache enable | |
|  |  | Bit 2 = Data cache write allocate policy (1=allocate) | |
| 1 | dp | Direct page register – 32 bit mode | |
| … |  |  |  |
| 3 | ph | Multiplier product high order 32 bits | |
| 4 | tick | Tick counter | Read only |
| 5 | lfsr | Linear feedback shift register | Pseudo random |
| 6 | dp8 | Direct page register – eight bit mode | |
| 8 | vbr | Vector base register – the lower 9 bits are always zero  Bit 0 = interrupt policy (1=native mode for all external interrupts) | |
| 14 | sp8 | 8 bit mode stack pointer | Upper 24 bits set the stack page |
| 15 | sp | Native mode Stack pointer |  |
|  |  |  |  |

## Addressing Modes

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | Clock Cycles |  |
| Rn | Register direct | 2 |  |
| #imm8 | Eight bit sign extended immediate | 2 |  |
| #imm16 | Sixteen bit sign extended immediate | 2 |  |
| #imm32 | Thirty-two bit immediate | 2 |  |
| zp,Rb | Zero page indexed | 4 |  |
| (zp,Rb) | Zero page indexed indirect (inner indexed) | 5 |  |
| (zp),Rb | Zero page indirect indexed (outer indexed) | 6 |  |
| abs | absolute | 4 |  |
| abs,Rb | Absolute indexed | 4 |  |
| (Rb) | Register indirect | 4 |  |
| Label | Relative branch | 2 |  |

## Memory Addressing

The cpu is word oriented for data and byte oriented for code. Up to 4GW of data are supported and 4GB of code.

The byte load/store instructions can address only the lower 4GB of the address space.

# Vectors

The processor vectors through $0FFFFFFF8 on a reset, and $0FFFFFFF4 on a non-maskable interrupt. In 32 bit mode, or with native mode on interrupt set, all other vectoring is done through a vector table. The vector table allows for 512 entries. The vector table base address is established by the VBR register. During an external IRQ the processor looks at a vector number bus to determine the vector to use for the IRQ. This vector number may be hard-coded in which case all IRQ’s will be vectored to the same location.

In eight bit mode the IRQ/BRK vectors through the usual eight bit IRQ vector at $0FFFE.

### Native mode vector table:

|  |  |  |  |
| --- | --- | --- | --- |
| Vector Number | Usage / Description |  |  |
| 0 | BREAK instruction vector |  |  |
| 1 | SLEEP vector (branch to self) |  |  |
| … |  |  |  |
| 448 |  |  |  |
| 449 | IRQ level 1 |  |  |
| … | Other IRQ levels |  |  |
| 463 | IRQ level 15 |  |  |
| … |  |  |  |
| 511 |  |  |  |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ADD | | Flags: v c n z | | | | | | | | | Bytes | Cyc |
| Byte 7 | Byte 6 | | Byte5 | Byte 4 | Byte 3 | | Byte 2 | | Byte 1 |  |  |  |
|  | | | | | 0 | Rt | Rb | Ra | 02h | ADD Rt,Ra,Rb | 3 | 2 |
|  | | | | | Imm8 | | Rt | Ra | 65h | ADD Rt,Ra,#imm8 | 3 | 2 |
|  | | | | Imm16 | | | Rt | Ra | 79h | ADD Rt,Ra,#imm16 | 4 | 2 |
|  | | Imm32 | | | | | Rt | Ra | 69h | ADD Rt,Ra,#imm32 | 6 | 2 |
|  | | | | Addr12 | | Rt | Rb | Ra | 75h | ADD Rt,Ra,zp,Rb | 4 | 4 |
|  | | | | Addr12 | | Rt | Rb | Ra | 61h | ADD Rt,Ra,(zp,Rb) | 4 | 5 |
|  | | | | Addr12 | | Rt | Rb | Ra | 71h | ADD Rt,Ra,(zp),Rb | 4 | 6 |
|  | | Addr32 | | | | | Rt | Ra | 6Dh | ADD Rt,Ra,abs | 6 | 4 |
| Addr32 | | | | | ~4 | Rt | Rb | Ra | 7Dh | ADD Rt,Ra,abs,Rb | 7 | 4 |
|  | | | | | ~4 | Rt | Rb | Ra | 72h | ADD Rt,Ra,(Rb) | 3 | 4 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| SUB | Flags: v c n z | | | | | | | | | | | Bytes | Cyc |
|  | |  | | 1 | | | Rt | Rb | Ra | 02h | SUB Rt,Ra,Rb | 3 | 2 |
|  | |  |  | | Imm8 | | | Rt | Ra | E5h | SUB Rt,Ra,#imm8 | 3 | 2 |
|  | |  | Imm16 | | | | | Rt | Ra | F9h | SUB Rt,Ra,#imm16 | 4 | 2 |
|  | Imm32 | | | | | | | Rt | Ra | E9h | SUB Rt,Ra,#imm32 | 6 | 2 |
|  | |  | Addr12 | | | Rt | | Rb | Ra | F5h | SUB Rt,Ra,zp,Rb | 4 | 4 |
|  | |  | Addr12 | | | Rt | | Rb | Ra | E1h | SUB Rt,Ra, (zp,Rb) | 4 | 5 |
|  | |  | Addr12 | | | Rt | | Rb | Ra | F1h | SUB Rt,Ra, (zp),Rb | 4 | 6 |
|  | Addr32 | | | | | | | Rt | Ra | EDh | SUB Rt,Ra,abs | 6 | 4 |
| Addr32 | | | | |  | Rt | | Rb | Ra | FDh | SUB Rt,Ra,abs,Rb | 7 | 4 |
|  | | | | ~4 | | | Rt | Rb | Ra | F2h | SUB Rt,Ra, (Rb) | 3 | 4 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| CMP | Flags: c n z | | | | | | | | | | | Bytes |
|  | |  | | 1 | | | 0 | Rb | Ra | 02h | CMP Ra,Rb | 3 |
|  | |  |  | | Imm8 | | | 0 | Ra | E5h | CMP Ra,#imm8 | 3 |
|  | |  | Imm16 | | | | | 0 | Ra | F9h | CMP Ra,#imm16 | 4 |
|  | Imm32 | | | | | | | 0 | Ra | E9h | CMP Ra,#imm32 | 6 |
|  | |  | Addr12 | | | 0 | | Rb | Ra | F5h | CMP Ra,zp,Rb | 4 |
|  | |  | Addr12 | | | 0 | | Rb | Ra | E1h | CMP Ra, (zp,Rb) | 4 |
|  | |  | Addr12 | | | 0 | | Rb | Ra | F1h | CMP Ra, (zp),Rb | 4 |
|  | Addr32 | | | | | | | 0 | Ra | EDh | CMP Ra,abs | 6 |
| Addr32 | | | | |  | 0 | | Rb | Ra | FDh | CMP Ra,abs,Rb | 7 |
|  | | | | ~4 | | | 0 | Rb | Ra | F2h | CMP Ra, (Rb) | 3 |
|  | | | | | | | | Imm8 | | C5h | CMP #imm8 | 2 |

CMP is an alternate mnemonic for SUB where the target register is R0. CMP does not affect the overflow flag.

* Opcode C5h compares the accumulator to a sign extended eight bit value.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| AND | Flags: n z | | | | | | | | | | | Bytes |
|  | |  | | 3 | | | Rt | Rb | Ra | 02h | AND Rt,Ra,Rb | 3 |
|  | |  |  | | Imm8 | | | Rt | Ra | 25h | AND Rt,Ra,#imm8 | 3 |
|  | |  | Imm16 | | | | | Rt | Ra | 39h | AND Rt,Ra,#imm16 | 4 |
|  | Imm32 | | | | | | | Rt | Ra | 29h | AND Rt,Ra,#imm32 | 6 |
|  | |  | Addr12 | | | Rt | | Rb | Ra | 35h | AND Rt,Ra,zp,Rb | 4 |
|  | |  | Addr12 | | | Rt | | Rb | Ra | 21h | AND Rt,Ra, (zp,Rb) | 4 |
|  | |  | Addr12 | | | Rt | | Rb | Ra | 31h | AND Rt,Ra, (zp),Rb | 4 |
|  | Addr32 | | | | | | | Rt | Ra | 2Dh | AND Rt,Ra,abs | 6 |
| Addr32 | | | | |  | Rt | | Rb | Ra | 3Dh | AND Rt,Ra,abs,Rb | 7 |
|  | | | | ~4 | | | Rt | Rb | Ra | 32h | AND Rt,Ra, (Rb) | 3 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| BIT | Flags: v n z | | | | | | | | | | | Bytes |
|  | * Bit is the AND operation with no target register; the overflow status is set to bit 30 of the result | | | | | | | | | | |  |
|  | |  | | 3 | | | 0 | Rb | Ra | 02h | BIT Ra,Rb | 3 |
|  | |  |  | | Imm8 | | | 0 | Ra | 25h | BIT Ra,#imm8 | 3 |
|  | |  | Imm16 | | | | | 0 | Ra | 39h | BIT Ra,#imm16 | 4 |
|  | Imm32 | | | | | | | 0 | Ra | 29h | BIT Ra,#imm32 | 6 |
|  | |  | Addr12 | | | 0 | | Rb | Ra | 35h | BIT Ra,zp,Rb | 4 |
|  | |  | Addr12 | | | 0 | | Rb | Ra | 21h | BIT Ra, (zp,Rb) | 4 |
|  | |  | Addr12 | | | 0 | | Rb | Ra | 31h | BIT Ra, (zp),Rb | 4 |
|  | Addr32 | | | | | | | 0 | Ra | 2Dh | BIT Ra,abs | 6 |
| Addr32 | | | | |  | 0 | | Rb | Ra | 3Dh | BIT Ra,abs,Rb | 7 |
|  | | | | ~4 | | | 0 | Rb | Ra | 32h | BIT Ra, (Rb) | 3 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| OR | Flags: n z | | | | | | | | | | | Bytes |
|  | |  | | 5 | | | Rt | Rb | Ra | 02h | OR Rt,Ra,Rb | 3 |
|  | |  |  | | Imm8 | | | Rt | Ra | 05h | OR Rt,Ra,#imm8 | 3 |
|  | |  | Imm16 | | | | | Rt | Ra | 19h | OR Rt,Ra,#imm16 | 4 |
|  | Imm32 | | | | | | | Rt | Ra | 09h | OR Rt,Ra,#imm32 | 6 |
|  | |  | Addr12 | | | Rt | | Rb | Ra | 15h | OR Rt,Ra,zp,Rb | 4 |
|  | |  | Addr12 | | | Rt | | Rb | Ra | 01h | OR Rt,Ra, (zp,Rb) | 4 |
|  | |  | Addr12 | | | Rt | | Rb | Ra | 11h | OR Rt,Ra, (zp),Rb | 4 |
|  | Addr32 | | | | | | | Rt | Ra | 0Dh | OR Rt,Ra,abs | 6 |
| Addr32 | | | | |  | Rt | | Rb | Ra | 1Dh | OR Rt,Ra,abs,Rb | 7 |
|  | | | | ~4 | | | Rt | Rb | Ra | 12h | OR Rt,Ra, (Rb) | 3 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ORB | Flags: n z | | | | | | | | | Bytes |
|  | |  | Addr12 | | Rt | Rb | Ra | B5h | OR Rt,Ra,zp,Rb | 4 |
|  | Addr32 | | | | | Rt | Ra | ADh | OR Rt,Ra,abs | 6 |
| Addr32 | | | |  | Rt | Rb | Ra | BDh | OR Rt,Ra,abs,Rb | 7 |

The ORB instruction loads a byte from memory and zero extends it before performing an a OR operation. The address fields represent a byte address.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| EOR | Flags: n z | | | | | | | | | | | Bytes |
|  | |  | | 4 | | | Rt | Rb | Ra | 02h | EOR Rt,Ra,Rb | 3 |
|  | |  |  | | Imm8 | | | Rt | Ra | 45h | EOR Rt,Ra,#imm8 | 3 |
|  | |  | Imm16 | | | | | Rt | Ra | 59h | EOR Rt,Ra,#imm16 | 4 |
|  | Imm32 | | | | | | | Rt | Ra | 49h | EOR Rt,Ra,#imm32 | 6 |
|  | |  | Addr12 | | | Rt | | Rb | Ra | 55h | EOR Rt,Ra,zp,Rb | 4 |
|  | |  | Addr12 | | | Rt | | Rb | Ra | 41h | EOR Rt,Ra, (zp,Rb) | 4 |
|  | |  | Addr12 | | | Rt | | Rb | Ra | 51h | EOR Rt,Ra, (zp),Rb | 4 |
|  | Addr32 | | | | | | | Rt | Ra | 4Dh | EOR Rt,Ra,abs | 6 |
| Addr32 | | | | |  | Rt | | Rb | Ra | 5Dh | EOR Rt,Ra,abs,Rb | 7 |
|  | | | | ~4 | | | Rt | Rb | Ra | 52h | EOR Rt,Ra, (Rb) | 3 |

## Load and Store Instructions

Arithmetic and logical instructions can take a memory operand as the third operand of the instruction. This effectively turns all these instructions into load instructions. Hence there isn’t an explicit load instruction. The OR or EOR instructions can readily be used to perform a load operation.

Because addresses are word addresses, the address field in the instructions is normally shifted left twice resulting in a 34 bit data address. The only exception to this is the byte load and store instructions.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| LD | Flags: n z | | | | | | | | | | | Bytes |
|  | |  |  | | Imm8 | | | Rt | 0 | 05h | LD Rt,#imm8 | 3 |
|  | |  | Imm16 | | | | | Rt | 0 | 19h | LD Rt,#imm16 | 4 |
|  | Imm32 | | | | | | | Rt | 0 | 09h | LD Rt,#imm32 | 6 |
|  | |  | Addr12 | | | Rt | | Rb | 0 | 15h | LD Rt,zp,Rb | 4 |
|  | |  | Addr12 | | | Rt | | Rb | 0 | 01h | LD Rt, (zp,Rb) | 4 |
|  | |  | Addr12 | | | Rt | | Rb | 0 | 11h | LD Rt, (zp),Rb | 4 |
|  | Addr32 | | | | | | | Rt | 0 | 0Dh | LD Rt,abs | 6 |
| Addr32 | | | | |  | Rt | | Rb | 0 | 1Dh | LD Rt,abs,Rb | 7 |
|  | | | | ~4 | | | Rt | Rb | 0 | 12h | LD Rt, (Rb) | 3 |
|  | | | | | | | | Rt | Ra | 7Bh | LD Rt,Ra | 2 |

LD is an alternate mnemonic for the OR instruction where register Ra is zero.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| LB | Flags: n z | | | | | | | | | Bytes |
|  | |  | Addr12 | | Rt | Rb | Ra | B5h | LB Rt,Ra,zp,Rb | 4 |
|  | Addr32 | | | | | Rt | Ra | ADh | LB Rt,Ra,abs | 6 |
| Addr32 | | | |  | Rt | Rb | Ra | BDh | LB Rt,Ra,abs,Rb | 7 |

LB is an alternate mnemonic for the ORB instruction where register Ra is zero.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| LDA | Flags: n z | | | | | | | | | | | Bytes |
|  | |  |  | | Imm8 | | | 1 | 0 | 05h | LDA #imm8 | 3 |
|  | |  | Imm16 | | | | | 1 | 0 | 19h | LDA #imm16 | 4 |
|  | Imm32 | | | | | | | 1 | 0 | 09h | LDA #imm32 | 6 |
|  | |  | Addr12 | | | 1 | | Rb | 0 | 15h | LDA zp,Rb | 4 |
|  | |  | Addr12 | | | 1 | | Rb | 0 | 01h | LDA (zp,Rb) | 4 |
|  | |  | Addr12 | | | 1 | | Rb | 0 | 11h | LDA (zp),Rb | 4 |
|  | Addr32 | | | | | | | Rt | 0 | 0Dh | LDA abs | 6 |
| Addr32 | | | | |  | 1 | | Rb | 0 | 1Dh | LDA abs,Rb | 7 |
|  | | | | ~4 | | | 1 | Rb | 0 | 12h | LDA (Rb) | 3 |

LDA is an alternate mnemonic for the OR instruction where register Ra is zero and register Rt is one.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| LDX | Flags: n z | | | | | | | | | | | Bytes |
|  | |  |  | | Imm8 | | | 2 | 0 | 05h | LDX #imm8 | 3 |
|  | |  | Imm16 | | | | | 2 | 0 | 19h | LDX #imm16 | 4 |
|  | Imm32 | | | | | | | 2 | 0 | 09h | LDX #imm32 | 6 |
|  | |  | Addr12 | | | 2 | | Rb | 0 | 15h | LDX zp,Rb | 4 |
|  | |  | Addr12 | | | 2 | | Rb | 0 | 01h | LDX (zp,Rb) | 4 |
|  | |  | Addr12 | | | 2 | | Rb | 0 | 11h | LDX (zp),Rb | 4 |
|  | Addr32 | | | | | | | Rt | 0 | 0Dh | LDX abs | 6 |
| Addr32 | | | | |  | 2 | | Rb | 0 | 1Dh | LDX abs,Rb | 7 |
|  | | | | ~4 | | | 2 | Rb | 0 | 12h | LDX (Rb) | 3 |

LDX is an alternate mnemonic for the OR instruction where register Ra is zero and register Rt is two.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| LDY | Flags: n z | | | | | | | | | | | Bytes |
|  | |  |  | | Imm8 | | | 3 | 0 | 05h | LDY #imm8 | 3 |
|  | |  | Imm16 | | | | | 3 | 0 | 19h | LDY #imm16 | 4 |
|  | Imm32 | | | | | | | 3 | 0 | 09h | LDY #imm32 | 6 |
|  | |  | Addr12 | | | 3 | | Rb | 0 | 15h | LDY zp,Rb | 4 |
|  | |  | Addr12 | | | 3 | | Rb | 0 | 01h | LDY (zp,Rb) | 4 |
|  | |  | Addr12 | | | 3 | | Rb | 0 | 11h | LDY (zp),Rb | 4 |
|  | Addr32 | | | | | | | Rt | 0 | 0Dh | LDY abs | 6 |
| Addr32 | | | | |  | 3 | | Rb | 0 | 1Dh | LDY abs,Rb | 7 |
|  | | | | ~4 | | | 3 | Rb | 0 | 12h | LDY (Rb) | 3 |

LDY is an alternate mnemonic for the OR instruction where register Ra is zero and register Rt is three.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ST | Flags: none | | | | | | | | | Bytes |
|  | |  | Addr12 | | 0 | Rb | Ra | 95h | ST Ra,zp,Rb | 4 |
|  | |  | Addr12 | | 0 | Rb | Ra | 81h | ST Ra, (zp,Rb) | 4 |
|  | |  | Addr12 | | 0 | Rb | Ra | 91h | ST Ra, (zp),Rb | 4 |
|  | Addr32 | | | | | 0 | Ra | 8Dh | ST Ra,abs | 6 |
| Addr32 | | | |  | 0 | Rb | Ra | 9Dh | ST Ra,abs,Rb | 7 |
|  | | | | | | Rb | Ra | 92h | ST Ra, (Rb) | 2 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| SB | Flags: none | | | | | | | | | Bytes |
|  | |  | Addr12 | | 0 | Rb | Ra | 74h | SB Ra,zp,Rb | 4 |
|  | Addr32 | | | | | 0 | Ra | 9Ch | SB Ra,abs | 6 |
| Addr32 | | | |  | 0 | Rb | Ra | 9Eh | SB Ra,abs,Rb | 7 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| STA | Flags: none | | | | | | | | | Bytes |
|  | |  | Addr12 | | 0 | Rb | 1 | 95h | STA zp,Rb | 4 |
|  | |  | Addr12 | | 0 | Rb | 1 | 81h | STA (zp,Rb) | 4 |
|  | |  | Addr12 | | 0 | Rb | 1 | 91h | STA (zp),Rb | 4 |
|  | Addr32 | | | | | 0 | 1 | 8Dh | STA abs | 6 |
| Addr32 | | | |  | 0 | Rb | 1 | 9Dh | STA abs,Rb | 7 |
|  | | | | | | Rb | 1 | 92h | STA (Rb) | 2 |

STA is an alternate mnemonic for ST where the register to be stored is R1 (the accumulator).

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| STX | Flags: none | | | | | | | | | Bytes |
|  | |  | Addr12 | | 0 | Rb | 2 | 95h | STX zp,Rb | 4 |
|  | |  | Addr12 | | 0 | Rb | 2 | 81h | STX (zp,Rb) | 4 |
|  | |  | Addr12 | | 0 | Rb | 2 | 91h | STX (zp),Rb | 4 |
|  | Addr32 | | | | | 0 | 2 | 8Dh | STX abs | 6 |
| Addr32 | | | |  | 0 | Rb | 2 | 9Dh | STX abs,Rb | 7 |
|  | | | | | | Rb | 2 | 92h | STX (Rb) | 2 |

STX is an alternate mnemonic for ST where the register to be stored is R2 (the x index register). There are also additional short-hand forms for the STX instruction.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| STY | Flags: none | | | | | | | | | Bytes |
|  | |  | Addr12 | | 0 | Rb | 3 | 95h | STY zp,Rb | 4 |
|  | |  | Addr12 | | 0 | Rb | 3 | 81h | STY (zp,Rb) | 4 |
|  | |  | Addr12 | | 0 | Rb | 3 | 91h | STY (zp),Rb | 4 |
|  | Addr32 | | | | | 0 | 3 | 8Dh | STY abs | 6 |
| Addr32 | | | |  | 0 | Rb | 3 | 9Dh | STY abs,Rb | 7 |
|  | | | | | | Rb | 3 | 92h | STY (Rb) | 2 |

STY is an alternate mnemonic for ST where the register to be stored is R3 (the y index register). There are also additional short-hand forms for the STY instruction.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| STZ | Flags: none | | | | | | | | | Bytes |
|  | |  | Addr12 | | 0 | Rb | 0 | 95h | STZ zp,Rb | 4 |
|  | |  | Addr12 | | 0 | Rb | 0 | 81h | STZ (zp,Rb) | 4 |
|  | |  | Addr12 | | 0 | Rb | 0 | 91h | STZ (zp),Rb | 4 |
|  | Addr32 | | | | | 0 | 0 | 8Dh | STZ abs | 6 |
| Addr32 | | | |  | 0 | Rb | 0 | 9Dh | STZ abs,Rb | 7 |
|  | | | | | | Rb | 0 | 92h | STZ (Rb) | 2 |

STZ is an alternate mnemonic for ST where the register to be stored is R0.

## Shift Operations / Read-modify-write memory operations.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ASL | Flags: c n z | | | | | | | | | | | Bytes |
|  | |  | |  | | | |  |  | 0Ah | ASL acc | 1 |
|  | |  | |  | | | | Rt | Ra | 06h | ASL Rt,Ra | 2 |
|  | |  | |  | Addr12 | | | | Rb | 16h | ASL zp,Rb | 3 |
|  |  | | Addr32 | | | | | | | 0Eh | ASL abs | 5 |
|  | Addr32 | | | | | | | Rb | 0 | 1Eh | ASL abs,Rb | 6 |
|  |  | | | | Eh | | Rt | Rb | Ra | 02h | ASL Rt,Ra,Rb | 3 |
|  |  | | | | ~3 | Imm5 | | Rt | Ra | 24h | ASL Rt,Ra,#imm8 | 3 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ROL | Flags: c n z | | | | | | | | | Bytes |
|  | |  | |  | |  |  | 2Ah | ROL acc | 1 |
|  | |  | |  | | Rt | Ra | 26h | ROL Rt,Ra | 2 |
|  | |  | |  | Addr12 | | Rb | 36h | ROL zp,Rb | 3 |
|  |  | | Addr32 | | | | | 2Eh | ROL abs | 5 |
|  | Addr32 | | | | | Rb | 0 | 3Eh | ROL abs,Rb | 6 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| LSR | Flags: c n z | | | | | | | | | | | Bytes |
|  | |  | |  | | | |  |  | 4Ah | LSR acc | 1 |
|  | |  | |  | | | | Rt | Ra | 46h | LSR Rt,Ra | 2 |
|  | |  | |  | Addr12 | | | | Rb | 56h | LSR zp,Rb | 3 |
|  |  | | Addr32 | | | | | | | 4Eh | LSR abs | 5 |
|  | Addr32 | | | | | | | Rb | 0 | 5Eh | LSR abs,Rb | 6 |
|  |  | | | | Fh | | Rt | Rb | Ra | 02h | LSR Rt,Ra,Rb | 3 |
|  |  | | | | ~3 | Imm5 | | Rt | Ra | 34h | LSR Rt,Ra,#imm8 | 3 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ROR | Flags: c n z | | | | | | | | | Bytes |
|  | |  | |  | |  |  | 6Ah | ROR acc | 1 |
|  | |  | |  | | Rt | Ra | 66h | ROR Rt,Ra | 2 |
|  | |  | |  | Addr12 | | Rb | 76h | ROR zp,Rb | 3 |
|  |  | | Addr32 | | | | | 6Eh | ROR abs | 5 |
|  | Addr32 | | | | | Rb | 0 | 7Eh | ROR abs,Rb | 6 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| INC | Flags: n z | | | | | | | | | Bytes |
|  | |  | |  | |  |  |  |  |  |
|  | |  | |  | | Rt | Ra | E6h | INC Rt,Ra | 2 |
|  | |  | |  | Addr12 | | Rb | F6h | INC zp,Rb | 3 |
|  |  | | Addr32 | | | | | EEh | INC abs | 5 |
|  | Addr32 | | | | | Rb | 0 | FEh | INC abs,Rb | 6 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| DEC | Flags: n z | | | | | | | | | Bytes |
|  | |  | |  | |  |  |  |  |  |
|  | |  | |  | | Rt | Ra | C6h | DEC Rt,Ra | 2 |
|  | |  | |  | Addr12 | | Rb | D6h | DEC zp,Rb | 3 |
|  |  | | Addr32 | | | | | CEh | DEC abs | 5 |
|  | Addr32 | | | | | Rb | 0 | DEh | DEC abs,Rb | 6 |

X index register short-form instructions.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| LDX | Flags: n z | | | | | | | | | Bytes | Cyc |
|  | |  | Immediate32 | | | | | A2h | LDX #i32 | 5 | 2 |
|  | |  | | | Immediate16 | | | B2h | LDX #i16 | 3 | 2 |
|  | |  | | | | Immediate8 | | A6h | LDX #i8 | 2 | 2 |
|  | |  | |  | Addr12 | | Rb | B6h | LDX zp,Rb | 3 |  |
|  |  | | Addr32 | | | | | AEh | LDX abs | 5 |  |
|  | Addr32 | | | | | Rb | 0 | BEh | LDX abs,Rb | 6 |  |
| STX | Flags: | | | | | | | | | Bytes |  |
|  | |  | |  | Addr12 | | Rb | 96h | STX zp,Rb | 3 |  |
|  |  | | Addr32 | | | | | 8Eh | STX abs | 5 |  |
| CPX | Flags: c n z | | | | | | | | | Bytes |  |
|  | |  | Immediate32 | | | | | E0h | CPX #i32 | 5 |  |
|  | |  | |  | Addr12 | | Rb | E4h | CPX zp,Rb | 3 |  |
|  |  | | Addr32 | | | | | ECh | CPX abs | 5 |  |
| INX | Flags: n z | | | | | | | E8h | INX | 1 |  |
| DEX | Flags: n z | | | | | | | CAh | DEX | 1 |  |
| PHX | Flags: | | | | | | | DAh | PHX | 1 |  |
| PLX | Flags: | | | | | | | FAh | PLX | 1 |  |

Y index register short-form instructions.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| LDY | Flags: n z | | | | | | | | | Bytes |
|  | |  | Immediate32 | | | | | A0h | LDY #i32 | 5 |
|  | |  | |  | Addr12 | | Rb | B4h | LDY zp,Rb | 3 |
|  |  | | Addr32 | | | | | ACh | LDY abs | 5 |
|  | Addr32 | | | | | Rb | 0 | BCh | LDY abs,Rb | 6 |
| STY | Flags: | | | | | | | | | Bytes |
|  | |  | |  | Addr12 | | Rb | 94h | STY zp,Rb | 3 |
|  |  | | Addr32 | | | | | 8Ch | STY abs | 5 |
| CPY | Flags: c n z | | | | | | | | | Bytes |
|  | |  | Immediate32 | | | | | C0h | CPY #i32 | 5 |
|  | |  | |  | Addr12 | | Rb | C4h | CPY zp,Rb | 3 |
|  |  | | Addr32 | | | | | CCh | CPY abs | 5 |
| INY | Flags: n z | | | | | | | C8h | INY | 1 |
| DEY | Flags: n z | | | | | | | 88h | DEY | 1 |
| PHY | Flags: | | | | | | | 5Ah | PHY | 1 |
| PLY | Flags: | | | | | | | 7Ah | PLY | 1 |

## Flow Control

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| JMP | Flags: | | | | | | | | | | Bytes | Cyc |
|  | |  | Address32 | | | | | | 5Ch | JMP abs | 5 | 2 |
|  | |  | | | Address16 | | | | 4Ch | JMP abs | 3 | 2 |
|  | |  | Address32 | | | | | | 6Ch | JMP (abs) | 5 |  |
|  | |  | Address32 | | | | | | 7Ch | JMP (abs,x) | 5 |  |
|  | |  |  | | | 0 | | Ra | D2h | JMP (Rn) | 2 | 2 |
| JSR | Flags: | | | | | | | | | | Bytes |  |
|  | |  | Address32 | | | | | | 22h | JSR abs | 5 |  |
|  | |  | | | Address16 | | | | 20h | JSR abs | 3 |  |
|  | |  | Address32 | | | | | | FCh | JSR (abs,x) | 5 |  |
|  | |  |  | | | 0 | | Ra | C2h | JSR (Rn) | 2 |  |
| RTS | Flags: | | | | | | | | 60h | RTS | 1 |  |
| RTI | Flags: z n c v b d i | | | | | | | | 40h | RTI | 1 |  |
| BRA | Flags: | | | | | | Disp8 | | 80h | BRA disp | 2 | 2 |
| BEQ | Flags: | | | | | | Disp8 | | F0h | BEQ disp | 2 | 2 |
| BNE | Flags: | | | | | | Disp8 | | D0h | BNE disp | 2 | 2 |
| BPL | Flags: | | | | | | Disp8 | | 10h | BPL disp | 2 | 2 |
| BMI | Flags: | | | | | | Disp8 | | 30h | BMI disp | 2 | 2 |
| BVS | Flags: | | | | | | Disp8 | | 70h | BVS disp | 2 | 2 |
| BVC | Flags: | | | | | | Disp8 | | 50h | BVC disp | 2 | 2 |
| BCS | Flags: | | | | | | Disp8 | | B0h | BCS disp | 2 | 2 |
| BCC | Flags: | | | | | | Disp8 | | 90h | BCC disp | 2 | 2 |
| BEQ | Flags: | | | Disp16 | | | 01h | | F0h | BEQ disp | 4 | 2 |
| BNE | Flags: | | | Disp16 | | | 01h | | D0h | BNE disp | 4 | 2 |
| BPL | Flags: | | | Disp16 | | | 01h | | 10h | BPL disp | 4 | 2 |
| BMI | Flags: | | | Disp16 | | | 01h | | 30h | BMI disp | 4 | 2 |
| BVS | Flags: | | | Disp16 | | | 01h | | 70h | BVS disp | 4 | 2 |
| BVC | Flags: | | | Disp16 | | | 01h | | 50h | BVC disp | 4 | 2 |
| BCS | Flags: | | | Disp16 | | | 01h | | B0h | BCS disp | 4 | 2 |
| BCC | Flags: | | | Disp16 | | | 01h | | 90h | BCC disp | 4 | 2 |
| BRL | Flags: | | | | Disp16 | | | | 82h | BRL disp | 3 | 2 |
| BSR |  | | | | Disp16 | | | | 62h | BSR disp | 3 |  |
| BRK | Flags: b | | | | | | | | 00h | BRK | 1 |  |
| NOP | Flags: | | | | | | | | EAh | NOP | 1 | 2 |
| WAI | Flags: | | | | | | | | CBh | WAI | 1 | 2+ |
| STP | Flags: | | | | | | | | DBh | STP | 1 | 2 |

## Stack push and pop operations.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| PHP | Flags: | | | 08h | PHP | 1 |
| PHA | Flags: | | | 48h | PHA | 1 |
| PHX | Flags: | | | DAh | PHX | 1 |
| PHY | Flags: | | | 5Ah | PHY | 1 |
| PUSH | Flags: | ~4 | Ra | 0Bh | PUSH Ra | 2 |
| PLP | Flags: z c v n i b d | | | 28h | PLP | 1 |
| PLA | Flags: | | | 68h | PLA | 1 |
| PLX | Flags: | | | FAh | PLX | 1 |
| PLY | Flags: | | | 7Ah | PLY | 1 |
| POP | Flags: | Rt | ~4 | 2Bh | POP Rt | 2 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| CLC | Flags: c | 18h | CLC | 1 | 2 |
| SEC | Flags: c | 38h | SEC | 1 | 2 |
| CLV | Flags: v | B8h | CLV | 1 | 2 |
| CLI | Flags: i | 58h | CLI | 1 | 2 |
| SEI | Flags: i | 78h | SEI | 1 | 2 |
| CLD | Flags: d | D8h | CLD | 1 | 2 |
| SED | Flags: d | F8h | SED | 1 | 2 |
| EMM | Flags: m | FBh | EMM | 1 | 2 |

## Register to register transfer short forms.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| TAX | Flags: n z | | | | AAh | TAX | 1 | 2 |
| TXA | Flags: n z | | | | 8Ah | TXA | 1 | 2 |
| TAY | Flags: n z | | | | A8h | TAY | 1 | 2 |
| TYA | Flags: n z | | | | 98h | TYA | 1 | 2 |
| TAS | Flags: | | | | 1Bh | TAS | 1 | 2 |
| TSA | Flags: n z | | | | 3Bh | TSA | 1 | 2 |
| TYX | Flags: n z | | | | BBh | TYX | 1 | 2 |
| TXY | Flags: n z | | | | 9Bh | TXY | 1 | 2 |
| TSX | Flags: n z | | | | BAh | TSX | 1 | 2 |
| TXS | Flags: | | | | 9Ah | TXS | 1 | 2 |
| TRS | Flags: | Spr | Ra | | 8Bh | TRS Ra,spr | 2 | 2 |
| TSR | Flags: n z | Rt | | Spr | ABh | TSR spr,Rt | 2 | 2 |

Opcode Map – 32 bit mode

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | -0 | -1 | -2 | -3 | -4 | -5 | -6 | -7 | -8 | -9 | -A | -B | -C | -D | -E | -F |
| 0- | BRK | OR (d,r) | RR | ~ | TSW d,r | OR #i8 | ASL r,r | ~ | PHP | OR #i32 | ASL acc | PUSH r | TSW abs | OR abs | ASL abs | ~ |
| 1- | BPL disp | OR (d),r | OR (r) | ~ | TRW d,r | OR d,r | ASL d,r | ~ | CLC | OR #i16 | INA | TAS | TRW abs | OR abs,r | ASL abs,r | ~ |
| 2- | JSR abs16 | AND (d,r) | JSL abs | ~ | ASL #i8 | AND #i8 | ROL r,r | ~ | PLP | AND #i32 | ROL acc | POP r | ~ | AND abs | ROL abs | ~ |
| 3- | BMI disp | AND (d),r | AND (r) | ~ | LSR #i8 | AND d,r | ROL d,r | ~ | SEC | AND #i16 | DEA | TSA | ~ | AND abs,r | ROL abs,r | ~ |
| 4- | RTI | EOR (d,r) | ~ | ~ | ~ | EOR #i8 | LSR r,r | ~ | PHA | EOR #i32 | LSR acc | ~ | JMP abs16 | EOR abs | LSR abs | ~ |
| 5- | BVC disp | EOR (d),r | EOR (r) | ~ | ~ | EOR d,r | LSR d,r | ~ | CLI | EOR #i16 | PHY | ~ | JML abs | EOR abs,r | LSR abs,r | ~ |
| 6- | RTS | ADD (d,r) | BSR | ~ | ~ | ADD #i8 | ROR r,r | ~ | PLA | ADD #i32 | ROR acc | RTL | JMP (abs) | ADD abs | ROR abs | ~ |
| 7- | BVS disp | ADD (d),r | ADD (r) | ~ | SB d,r | ADD d,r | ROR d,r | ~ | SEI | ADD #i16 | PLY | LD r | JMP (abs,x) | ADD abs,r | ROR abs,r | ~ |
| 8- | BRA disp | ST (d,r) | BRL disp | ~ | ~ | ~ | ~ | ~ | DEY | ~ | TXA | TRS | STY abs | ST abs | STX abs | ~ |
| 9- | BCC disp | ST (d),r | ST (r) | ~ | STY d,r | ST d,r | STX d,r | ~ | TYA | ~ | TXS | TXY | SB abs | ST abs,r | SB abs,r | ~ |
| A- | LDY #i32 | ORB (d,r) | LDX #i32 | ~ | ~ | LDA #i8 | LDX #i8 | ~ | TAY | LDA #i32 | TAX | TSR | LDY abs | ORB abs | LDX abs | ~ |
| B- | BCS disp | ORB (d),r | LDX #i16 | ~ | LDY d,r | ORB d,r | LDX d,r | ~ | CLV | LDA #i16 | TSX | TYX | LDY abs,r | ORB abs,r | LDX abs,r | ~ |
| C- | CPY #i32 | BAZ | JSR (r) | ~ | CPY d,r | CMP #i8 | DEC r | ~ | INY | ~ | DEX | WAI | CPY abs | ~ | DEC abs | ~ |
| D- | BNE disp | BXZ | JMP (r) | ~ | ~ | ~ | DEC d,r | ~ | CLD | ~ | PHX | STP | ~ | ~ | DEC abs,r | ~ |
| E- | CPX #i32 | SUB (d,r) | ~ | ~ | CPX d,r | SUB #i8 | INC r | ~ | INX | SUB #i32 | NOP | ~ | CPX abs | SUB abs | INC abs | ~ |
| F- | BEQ disp | SUB (d),r | SUB(r) | ~ | ~ | SUB d,r | INC d,r | ~ | SED | SUB #i16 | PLX | EMM | JSR (abs,x) | SUB abs,r | INC abs,r | ~ |

Register-Register (RR) Instructions

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 02 | ADD | SUB | ~ | AND | EOR | OR | ~ | ~ | MUL | MULS | DIV | DIVS | MOD | MODS | ASL | LSR |

Opcode Map – 8 bit mode W65C02 compatible

|  |  |
| --- | --- |
|  | = Enhanced instructions not found on the 65C02 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | -0 | -1 | -2 | -3 | -4 | -5 | -6 | -7 | -8 | -9 | -A | -B | -C | -D | -E | -F |
| 0- | BRK | ORA (d,x) | ~ | ~ | TSB d,r | ORA d | ASL d | ~ | PHP | OR #i8 | ASL acc | ~ | TSB abs | ORA abs | ASL abs | ~ |
| 1- | BPL disp | ORA (d),y | ORA (d) | ~ | TRB d,r | OR d,x | ASL d,x | ~ | CLC | OR abs,y | INA | TAS | TRB abs | ORA abs,x | ASL abs,x | ~ |
| 2- | JSR abs | AND (d,x) | JSL abs32 | ~ | BIT d | AND d | ROL d | ~ | PLP | AND #i8 | ROL acc | ~ | BIT abs | AND abs | ROL abs | ~ |
| 3- | BMI disp | AND (d),y | AND (d) | ~ | BIT d,x | AND d,x | ROL d,x | ~ | SEC | AND abs,y | DEA | TSA | BIT abs,x | AND abs,x | ROL abs,x | ~ |
| 4- | RTI | EOR (d,x) | ~ | ~ | ~ | EOR d | LSR d | ~ | PHA | EOR #i8 | LSR acc | ~ | JMP abs | EOR abs | LSR abs | ~ |
| 5- | BVC disp | EOR (d),y | EOR (d) | ~ | ~ | EOR d,x | LSR d,x | ~ | CLI | EOR abs,y | PHY | ~ | JML abs32 | EOR abs,x | LSR abs,x | ~ |
| 6- | RTS | ADC (d,x) | ~ | ~ | STZ d | ADC d | ROR d | ~ | PLA | ADC #i8 | ROR acc | RTL | JMP (abs) | ADC abs | ROR abs | ~ |
| 7- | BVS disp | ADC (d),y | ADC (d) | ~ | STZ d,x | ADC d,x | ROR d,x | ~ | SEI | ADC abs,y | PLY | ~ | JMP (abs,x) | ADC abs,x | ROR abs,x | ~ |
| 8- | BRA disp | STA (d,x) | BRL disp | ~ | STY d | STA d | STX d | ~ | DEY | BIT # | TXA | ~ | STY abs | STA abs | STX abs | ~ |
| 9- | BCC disp | STA (d),y | STA (d) | ~ | STY d,x | STA d,x | STX d,y | ~ | TYA | STA abs,y | TXS | TXY | STZ abs | STA abs,x | STZ abs,x | ~ |
| A- | LDY #i8 | LDA (d,x) | ~ | ~ | LDY d | LDA d | LDX #i8 | ~ | TAY | LDA #i8 | TAX | ~ | LDY abs | LDA abs | LDX abs | ~ |
| B- | BCS disp | LDA (d),y | LDA (d) | ~ | LDY d,x | LDA d,x | LDX d,y | ~ | CLV | LDA abs,y | TSX | TYX | LDY abs,x | LDA abs,x | LDX abs,x | ~ |
| C- | CPY #i8 | CMP (d,x) | ~ | ~ | CPY d | CMP d | DEC d | ~ | INY | CMP #i8 | DEX | WAI | CPY abs | CMP abs | DEC abs | ~ |
| D- | BNE disp | CMP (d),y | CMP (d) | ~ | ~ | CMP d,x | DEC d,r | ~ | CLD | CMP abs,y | PHX | STP | ~ | CMP abs,x | DEC abs,x | ~ |
| E- | CPX #i8 | SBC(d,x) | ~ | ~ | CPX d | SUB d | INC d | ~ | INX | SBC #i8 | NOP | ~ | CPX abs | SBC abs | INC abs | ~ |
| F- | BEQ disp | SBC (d),y | SBC(r) | ~ | ~ | SUB d,x | INC d,r | ~ | SED | SBC abs,y | PLX | NAT | JSR (abs,x) | SBC abs,x | INC abs,x | ~ |